CRANFIELD UNIVERSITY

AISHA MOMOH

# A FRAMEWORK FOR COMPLEXITY COST MODELLING OF ERP IMPLEMENTATION

SCHOOL OF AEROSPACE, TRANSPORT AND MANUFACTURING

PhD
Academic Year: 2014 - 2015

Supervisor: Dr. Essam Shehab & Prof. Rajkumar Roy
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This thesis is submitted in partial fulfilment of the requirements for the degree of PhD

# ABSTRACT

The aim of this research is to develop a framework to predict the cost of the resource complexities inherent in an ERP implementation. The framework comprises two phases namely complexity assessment, and dynamic cost estimation for resource complexity using agent-based modelling. The complexity assessment phase involves complexity identification, uncertainty evaluation for the complexity estimates, complexity assessment, complexity classification, and complexity correlation reporting. The framework is automated in a tool known as Complexity of Resource and Assessment Costing Tool (C-REACT).

A number of activities have been undertaken in order to develop the ERP resource complexity framework. Firstly, a detailed literature review was performed in order to gain a contextual understanding of ERP implementation challenges and complexities. Secondly, a case study analysis was conducted to establish the current industrial practices concerning ERP implementation challenges. Thirdly, a framework was developed and validated to identify, assess and cost ERP complexity for each resource.

The key contribution of the framework is to introduce a new cost estimation process to support ERP project cost estimation by predicting the cost of ERP resource complexities, and a new process to identify, assess and control ERP complexities inherent in the implementation stage. This framework should be used in the needs identification stage of an ERP project lifecycle. The estimate will inform an organisation of the potential costs of ERP resources from a complexity perspective, thereby enabling them to make informed decisions on ERP implementation complexity and cost reduction. Knowledge of potential complexities will also aid the elimination of substantial errors during implementation. Hence the organisation will yield benefits which they would not otherwise reap in the face of complexity.

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# LIST OF PUBLICATIONS

1. Momoh, A., Roy, R., Shehab, E. (2010). Challenges in Enterprise Resource Planning Implementation: State-of-the-art. Business Process Management Journal, vol. 16, issue 4, pp. 537-565.

2. Momoh A., Roy R., Shehab E., Snowden D. (2007). “Challenges in Enterprise Resource Planning (ERP) Phased Approach Implementation within a Large Organisation: A Case Study”. *The 5th International Conference on Manufacturing Research (ICMR 2007)*, De Montfort University, Leicester, UK, 11th – 13th September 2007 ISBN 0-9553215-0-6, pp 265-271.

3. Momoh, A., Roy, R., Shehab, E. (2008). A WBS for Implementing and Costing an ERP Project. Communications of the IBIMA Journal, ISSN: 1943-7765, 6(15), 94-103.

4. Momoh A., Roy R and Shehab E. (2008) “A Work Breakdown Structure for Implementing and Costing an ERP Project” *The 10th IBIMA conference on Innovation and Knowledge Management in Business Globalization,* Kuala Lumpur, Malaysia 30 June – 2 July 2008.

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| | |
|---|---|
| AACE | Association of Advancement of Cost Engineering |
| ABC | Activity-Based Costing |
| ABM | Agent Based Modelling |
| AHP | Analytical Hierarchy Process |
| AIM | Application Implementation Methodology |
| ASAP | Accelerated Systems Applications Products |
| BAU | Business As Usual |
| BCS | Basic Control Structure |
| BPC | Business Process Complexity |
| CAS | Complex Adaptive Systems |
| CBS | Complexity Breakdown Structure |
| CBR | Case-Based Reasoning |
| CCM | Complexity Correlation Matrix |
| CFC | Control Flow Complexity |
| CFF | Critical Failure Factor |
| CFS | Cognitive Functional Size |
| CN | Cyclomatic Number |
| CRM | Customer Relationship Management |
| CSF | Critical Success Factor |
| DEA | Data Envelopment Analysis |
| DES | Discrete Event Simulation |
| DQ | Data Quality |
| DSM | Design Structure Matrix |
| ERP | Enterprise Resource Planning |
| FPA | Function Point Analysis |
| GP | Goal Programming |
| GSK | General System Characteristics |
| IM | Information Management |
| IS | Information Systems |
| ISM | Interpretive Structural Modelling |
| IT | Information Technology |
| IF | Information Flow |
| KCN | Kessington’s Complexity Number |
| LOC | Lines of Code |
| MAUT | Multi-Attribute Utility Theory |
| MAVT | Multi-Attribute Value Theory |
| MCDM | Multi Criteria Decision Making |
| MRP | Material Requirements Planning |
| MRP II | Manufacturing Resource Planning |
| NUSAP | Numeral Unit Spread Assessment Pedigree |
| PERT | Project Evaluation Review Technique |
| PMI | Project Management Institute |
| PRA | Probabilistic Risk Assessment |
| QTP | Quicktest Professional |
| RFP | Request for Proposal |
| ROI | Return on Investment |

| | |
|---|---|
| SA | Sensitivity Analysis |
| SAP | Systems Applications Products |
| SAW | Simple Additive Weighting |
| SCM | Supply Chain Management |
| SD | System Dynamics |
| SLA | Service Level Agreement |
| SMART | Multi-Attribute Rating Technique |
| SME | Subject Matter Expert |
| SoS | System of Systems |
| TCF | Technical Correction Factors |
| TCO | Total Cost of Ownership |
| TOPSIS | Technique for Order Preferences by Similarity to Ideal Solutions |
| UFP | Unadjusted Function Point |
| UUMII | Use Understand Manage Implement Increase |
| VAF | Value Adjustment Factor |
| WBS | Work Breakdown Structure |
| WLC | Whole Life Cycle |

# 1 INTRODUCTION

## 1.1 Research Background

In today's world, as supply chains, markets, and technology become global, program and project managers are increasingly encountering more and more complexity in programs and projects (PMI, 2014). The fundamental and rapid changes in societies and economies, including innovations in the manufacturing and delivery of products, have also increased complexity dramatically in projects (PMI, 2014). Enterprise Resource Planning (ERP) implementation projects are no exception to this problem. ERP is one of the most widely discussed subjects in research and industry. The essence of undertaking an ERP project is to produce a system which provides functional integration for an ERP adopter. These systems have traditionally been used by capital-intensive industries, such as manufacturing, construction, aerospace, and defense (Momoh *et al.*, 2007; Momoh *et al*., 2010; Chung *et al*., 2000). Several authors (May *et al.,* 2013; Shehab *et al*., 2004; Somers *et al.,* 2004; Momoh *et al.,* 2010; Palanisamy, 2007; Miragliotta *et al*., 2004; Wu *et al*., 2008; Laughlin, 1999; Sessions, 2011) have asserted that ERP systems are complex and have caused a substantial amount of failed implementations. To highlight the consequence of this view, Bansal *et al.* (2008) and Sessions (2011) emphasise that increased complexity causes an increase in implementation failure. Palanisamy (2007) asserts that these complexities in ERP solutions result in expensive implementations and present a big challenge for organisations. The increase in cost is substantial and often emerges unexpectedly (Abdullah *et al.,* 2014; Wu *et al*., 2008; Davenport, 1998; Reda, 1998; Jacob, 1999; Mabert *et al*., 2000; Ehie *et al.,* 2005; Momoh *et al*., 2010; Sessions, 2011). A substantial amount of an ERP implementation cost is often not originally anticipated, and one of the hidden and substantial costs is the consulting services employed to implement the ERP solution (Ehie, 2005; Vogt, 2002). Unforeseen complexities and difficulties are frequently encountered on ERP implementation projects, thereby leading to unexpected high costs (Vogt, 2002). These complexities increase the consultants' unanticipated effort in implementing the system, thereby causing an unexpected increase in the consultant's bill (Vogt, 2002), which is usually costly.

Marnewick and Labuschagne (2005) and Matidinos *et al.* (2012) assert that 25 percent of ERP installations exceed the initial cost, and about 20 percent cannot be completed. As a consequence of the ERP implementation cost, Elangovan *et al*. (2011) caution that ERP implementation projects are a risky undertaking. Hence, ERP systems have become one of today's largest IT investments ( Momoh *et* al., 2010; Chung *et* al., 2000).

### 1.1.1 ERP Complexity and its Impact on Cost

Implementing ERP systems entails fulfilling a number of components. The conceptual components of ERP depicted in Figure 1-1 illustrate that several key areas must be addressed in order for ERP to be implemented successfully. Each of the components requires immense focus, adequate, knowledgeable and skilled resources, and a thorough understanding of ERP and its impact on cost. Tackling all of these components is bound to give rise to complexities. In the researcher's experience, complexities trigger other complexities. It is no wonder that ERP implementations are rarely successful the first time around.


**Figure 1-1:** Conceptual Components of ERP (Adapted from Marnewick, 2005)

Although there seem to be a significant amount of research done in software development complexity, there is less research in ERP system implementation complexity. However, in industry, ERP complexity is continuously debated. Competition now involves producers as well as suppliers and distributors, thus making the overall system more complex to be managed (Miragliotta *et al*., 2004). Thus Miragliotta *et al*. (2004) assert that the control and management of this increasing level of complexity can be regarded as a strategic issue for companies. But the challenge is in understanding the meaning of complexity (Sessions, 2011) and how it impacts ERP. There is a difficulty in understanding the complex factors involved in ERP adoption decision (Elangovan *et* al., 2011). The PMI (2014) highlight that the anticipation of the effects of complexity and the management of actions to meet the challenges of complexity require understanding its causes and how it is experienced. Without this understanding, ERP complexity will remain a challenge to identify, measure and control.

There are a number of definitions on complex systems. Apparently, past researchers have confounded the concept of complexity with novelty, uncertainty, ambiguity, difficulty and other concepts which are potentially related to, but distinct from complexity itself (Jacobs, 2013).

Simpson *et al*. (2010), Jacobs (2013) and Sessions (2011) associate complexity with difficulty. Simpson *et al.* (2010) define complexity as a measure of the difficulty and/or effort and/or resources required for one system to effectively observe, communicate and/or interoperate with another system. Sessions (2011) define complexity as the attribute of a system that makes that system difficult to use, understand, manage, and/or implement. Miragliotta *et al*. (2004) define complexity in terms of systems that are made up by single elements which have intimate connections, counterintuitive and non-linear links; as a consequence, complex systems present self-emerging, often chaotic, behaviours. Complexity is increased with greater multiplicity of elements (Jacobs, 2013; Sessions, 2011) as presented in Figure 1-2. Sessions (2011) cautions that complexity is exponential, and increases with the size of an IT project.

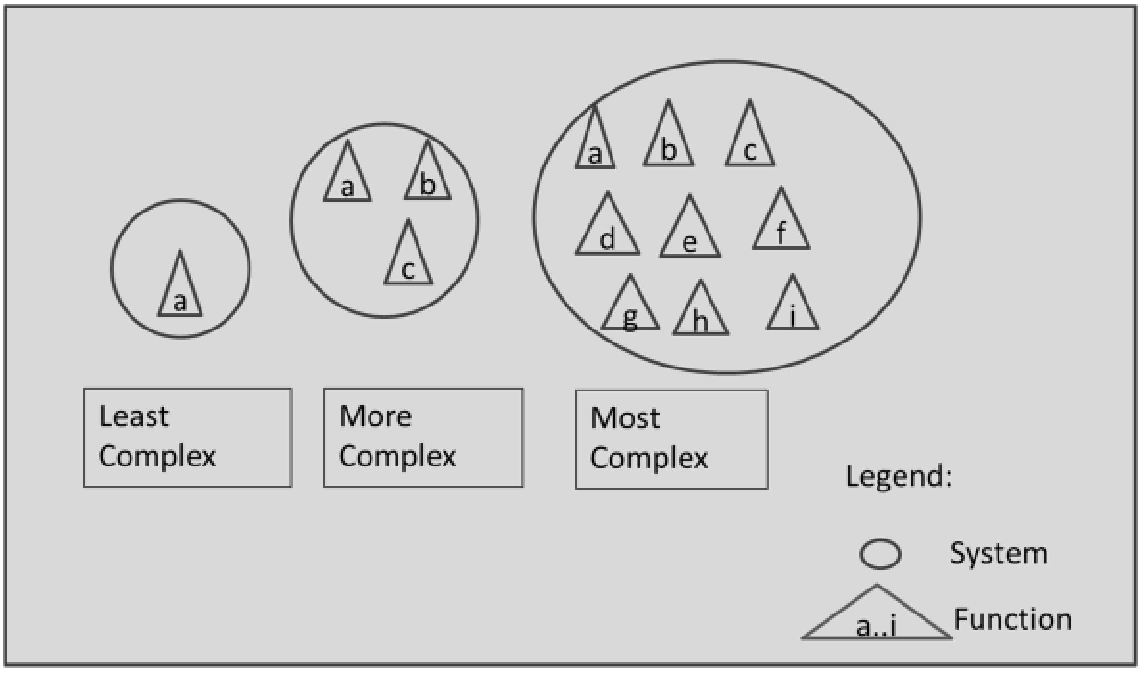



**Figure 1-2:** Increasing Complexity with Increasing Functionality (Adapted from Sessions, 2011)

Complexity and cost are intimately connected (Sessions, 2011). In support of this stipulation, Phukan *et al*. (2005) emphasise that software complexity is the major reason for rapidly increasing software development costs. This also applies to ERP implementations which can run into hundreds of millions of dollars. Allied Waste Industries, Inc. decided to pull the plug on a $130 million system built around SAP R/3 (Kim *et al*., 2005). Another costly implementation was reported by Kanaracus (2011) about the Ingram Micro ERP implementation which caused a net income reduction of $14 million due to difficulties encountered in the process of transitioning to a new system. This indicates why so many organisations pull out of ERP implementations, or fail completely. The researcher has encountered an implementation which cost approximately $18 million.  This implementation spanned two years and overran its schedule, and during this period, the ERP system still had not been transformed into an operational system.  The implementation was very complex. Eventually, the ERP adopter cancelled the project and undertook a re-implementation with less complexity.  As Phukan *et al.* (2005) has stipulated that software complexity increases software development costs, it can be concluded that complexity drives cost.  Therefore, to reduce the cost of an implementation, a complexity reduction must be accomplished.

### 1.1.2 Complexity in the ERP Implementation Stage

An organisation incurs most of its ERP project cost in the implementation stage. This is where the business processes are analysed, designed, built and tested. The required data is also cleansed and converted in this phase, and this activity is one of the areas with hidden costs; the effort required in fulfilling a good level of data quality is often underestimated.  Additionally, the stakeholders of the system are trained in this phase.  And the data is migrated into the live system for use by the ERP adopting organisation.  Figure 1-3 illustrates the different activities in the implementation stage.  Each phase entails its own complexity which triggers one or more complexities in other phases.

The illustration of so many critical activities in the implementation phase is an indication of a variety of complexities.  As Jacobs (2013) and Sessions (2011) have asserted that complexity is increased with greater multiplicity of elements and increases with the size of an IT project, it is inferred in this research that complexity is increased with an increase in activity.  Also, emerging complexities result in increased implementation cost.  Therefore, each activity should be monitored, controlled, executed and managed effectively.  To accomplish this goal, each activity will require substantial time and effort, and most fundamentally, skilled resources.

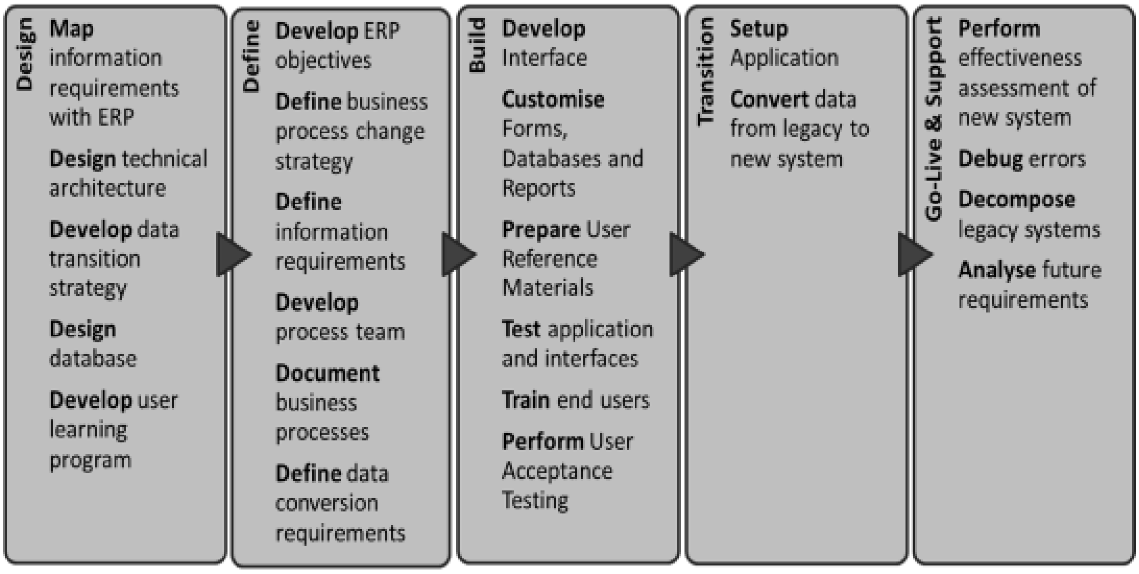



**Figure 1-3:** Phases of ERP Implementation (Adapted from Nazir, 2005)

### 1.1.3 Complexity in ERP Implementation Resources

Success of any project critically depends on its team members (Kumar *et al*., 2002). The lack of experienced consultants and trained employees in ERP philosophy represents a serious constraint that could jeopardise the implementation project (Stefanou, 2001). Therefore, it is vital that competent resources, both internal and external, are used to implement an ERP solution. However, irrespective of the competence level of a resource, they will encounter the complexities which emerge in the implementation phase of an ERP project. Consequently, these implementations might fail. In some cases, the complexities might be encountered because the resources are inexperienced, and in other cases, the complexities might arise simply because ERP in itself is a complex system. In the face of this problem, it is difficult to discern the source of the complexity or its increase, as the case may be. When this occurs, it is a challenge to control the cost because of increased complexity.

In a survey conducted by Kumar *et* al (2002), it was observed that consulting dollars represented as high as 70% of the total project costs in one project. In their survey, high consultant costs later became one of the prominent reasons for upward revision of project budget (Kumar *et al*., 2002). Consulting fees, which is embedded in resource costs, is notorious for being a hidden cost. Hence it is imperative to cost ERP complexity from a project resource perspective. Pizzi *et al. (*2004) imply that building software of high complexity requires a lot of effort. But firstly, there is a need to develop metrics to quantify complexity (Phukan *et al*., 2005; Jacobs, 2013). In terms of complexity metrics, research in software development is more advanced than ERP implementation. Pizzi *et al.* (2004) assert that a lot of research is dedicated to defining different software measures that capture software complexity. Complexity of software is an important part of development activities (Pizzi *et al.,* 2004).

This research intends to develop a framework to identify and quantify the complexities encountered by ERP project resources in the implementation phase, and to estimate the cost of this complexity. The framework is embedded in a software tool known as Complexity of Resource and Assessment Costing Tool (C-REACT) which will be used by ERP adopters to estimate the resource complexity cost of a potential implementation in the needs identification stage of an ERP project life cycle. This will aid the ERP adopters in preparing their budget for the ERP project. It will also present them with the complexities which they might face during implementation, thereby enabling them to prepare for complexity management and reduction which will consequently reduce cost. The ERP adopters will be empowered to use the framework to manage their resource cost by managing the complexities. ERP consultancies will also use the framework to bid for ERP projects.

## 1.2 Research Motivation and Scope

In the ERP industry, numerous implementation failures have been encountered. For over a decade, most organisations struggled to identify the causes of the failures. Then there was a sudden surge of research into the source of ERP implementation failures. Most of the research initially focussed on ERP Critical Success Factors (CSF). At the time, very little was done to counteract these failures as realisation was only just setting in through research. To compound the challenges, ERP costs were rising uncontrollably, sometimes into the hundreds of millions of dollars. With the passage of time, it has become very apparent that ERP solutions are simply complex to implement. And complexity translates to cost. Therefore, increased complexity results in increased cost.

ERP complexities are manifested in various ways, and in most cases, they are unanticipated by both management and project resources. It is the lack of anticipation, identification and understanding of these complexities that cause implementations to fail and the consequence is a cost and time overrun. Due to a lack of a framework to anticipate and control the complexities, the continuous and unexpected increase in cost and time overrun sometimes forces organisations to go into bankruptcy. This research seeks to develop a framework which identifies, assesses, and costs the complexities experienced by resources in the implementation stage of an ERP whole life cycle project. The framework will enable organisations to anticipate the implementation resource complexity cost in the needs identification stage, and be well prepared to control and reduce the complexities in the implementation stage. This will result in an ERP implementation cost reduction and will maximise ROI (Return on Investment).

The focus of this research is on ERP implementations for large ERP organisations. The output of the research is a framework which will be used to assess and estimate the resource complexity cost of a potential ERP implementation. The developed framework C-REACT is used by ERP adopters in the Needs Identification stage of an ERP project whole life cycle.

## 1.3 Research Aim and Objectives

This research aims to develop a framework which predicts the cost of the resource complexities of an ERP implementation. The framework will support and improve the ERP cost estimation process in the needs identification stage of an ERP project whole life cycle. An additional process for complexity identification and assessment has been introduced into this stage. The complexity of resource and assessment costing tool (C-REACT) enables well informed investment decision making in the acquisition and ownership of an ERP application.

The main objectives of the research are to:

- Investigate the complexity factors inherent in ERP implementations which will define a complexity taxonomy that enables the identification of complexities for resource complexity assessment and cost estimation
- Design a work breakdown structure for ERP implementation activities and resources for which the complexity cost will be estimated
- Develop a technique for assessing ERP complexity
- Analyse the cost drivers which enable the costing of complexity in ERP implementations in order to support the cost estimation of resource complexity
- Design and develop a framework for assessing ERP implementation complexities to support in identifying, understanding and preparing for potential ERP implementation resource complexities
- Design and develop a framework for the dynamic cost estimation of resource complexity to support in predicting potential ERP implementation cost
- Verify and validate the proposed frameworks through real life industrial case studies and experts' opinion

## 1.4 Collaborating Organisations

The main organisations that participated in this research project are: Rolls Royce PLC, Sahara Energy Limited, Philips, Transport for London (TfL), Yara

Fertiliser, OANDO Plc., Oceanic Bank International Plc., Northgate Arinso (NGA), aSource Global, Company B, Company C, Universal Pictures, Soft Alliance and Resources, and Company L. Four of these organisations; NGA, aSource Global, Soft Alliance and Resources, and Company C, are ERP consultancies. The remaining organisations are ERP adopters in transport, aerospace and defence, oil and gas, banking, chemical production and entertainment. Companies B, C and L have requested to remain anonymous.

One of these organisations assisted the researcher in gaining an overall conceptual understanding of the research subject and its current situation in industry. The rest participated in the iterative design and development of the ERP resource complexity cost framework. And five of them collaborated on the validation of the framework.

### 1.4.1 Transport for London

Transport for London (TfL) was created in 2000 as the integrated body responsible for the Capital's transport system. It is a local authority organisation that also constitutes commercial arms and makes a significant income of approximately two billion pounds yearly. This covers half its expenditure. The purpose of being commercial is to obtain income for use in spending more efficiently on the customer.

TfL is made up of four modes, further constituting twelve to fourteen operating entities:

- TfL Corporate (head office where all corporate functions are performed)
- London Underground (LU)
- Surface Trains (ST)
- London Rail (LR)

The nature of the business in TfL is quite diverse. It focuses on integrated transport and encourages the use of river, bus, walking, cycling, etc. The business transcends generating revenue for the services provided; TfL addresses how to get London moving and how best to move people around London. The organisation also focuses on how best to provide the strategy to allow this to happen in a variety of different ways and different modes.

### 1.4.2 Rolls Royce PlC.

Rolls Royce Group is a global provider of complex and integrated power systems to the aerospace and marine/industrial power system markets. It was first established in 1884. The organisation owns two strong technology platforms which are gas turbines and reciprocating engines. Its consistent and long-term strategy has experienced a doubling in revenue and an increase in underlying profit more than five times in the last decade. In 2014, its order book reported the amount of £73.7 billion and an underlying revenue of £13,864 billion.

As part of its strategy to harmonise its systems and increase manufacturing capacity, Rolls Royce implemented SAP. This was accomplished through a two-year implementation project across 29 sites. The system is used by 20,000 staff. SAP enables the Rolls Royce group to run its manufacturing operations, project management, human resources, material requirements planning, and financial systems. Although there was very little modification for the SAP solution, the diversity and globalisation of the implementation introduced its own complexities.

### 1.4.3 Sahara Oil PlC.

What is now known today as Sahara is an oil and gas group which started in 1996 as a single company named Sahara Energy Limited. It was founded as an oil trading business. Within 3 years the company had established herself as a credible trading house securing trade lines from first class international banks.

As the company grew, there was a need to diversify into other industry-related businesses. This need initially gave birth to the creation of divisions. However, due to their individual successes the divisions became separate limited liability companies, each with its own management and organizational structure, all co-existing as a part of the larger Group.

The Sahara Group has its head office in Lagos and has business activities that span through the entire energy value chain, with the Oil and Gas sector as well as associated sub-sectors as its core field of operations. The Group also participates in businesses in other industries that are synergistic to its core field and those businesses deemed strategic in its regions of operation.

The Group has witnessed remarkable growth since its inception and have successfully spun off 4 fully autonomous affiliate companies, leaving 13 operating companies under the Group umbrella. They have a total of 20 operating companies. Their offices span Switzerland, United Kingdom, Singapore, UAE, Nigeria, Ghana and Cote D'Ivoire. They have a current staff strength of 610, and their annual turnover as at 2012 was in excess of $11.4 billion.

Sahara Energy Limited selected Oracle as their ERP solution. They commenced their implementation in 2007, and declared it a failure in 2008. They re-implemented their ERP system in 2010 with less complexities than their prior implementation. They now have a successful productive system.

### 1.4.4 Company B

The objectives of this organisation are to strengthen a country and its interest, and to maintain international peace. It implements the defence policy set for the coutry where it was built. This organisation manages the day-to-day running of its armed forces, contingency planning and defence procurement.

The governance of Company B focuses on a board, a council, central command organisations, support organisations, executive agencies, and non-departmental public organisations.

Company B implemented both SAP and Oracle ERP solutions. Due to the magnitude of the implementation, it was considered extremely complex.

### 1.4.5 aSource Global

aSource Global is focused on management consultancy which specialises in providing services for regulatory compliance and risk in the financial services sector. They also specialise in IT for business change and transformation, and infrastructure and services. Additionally, aSource Global specialises in collateral management and project portfolio management for the banking and insurance industries. The company also provides resource services.

### 1.4.6 Yara International

Yara is a leading global chemical company that converts energy, natural minerals and nitrogen from the air into essential products for farmers and industrial customers. As the world's largest supplier of mineral fertilizers and ammonia, Yara is dedicated to boosting food production and providing bioenergy for a growing and more affluent world population. The company's development is rooted in that of Norwegian industrial firm Norsk Hydro, which dates back to 1905. That's when industrialists Sam Eyde, Kristian Birkeland and Marcus Wallenberg tapped into Norway's large hydro energy resources to produce the company's first important product: Mineral fertilizer, which attracted attention from all over the world since it enabled farmers to boost their yields.

With its Head Office in Oslo Norway, Yara employs about 7,600 persons with operations and offices in more than 50 countries. Yara is the world's largest supplier of crop nutrients with sales to more than 120 countries and it raked in revenue of 61.5 billion Norwegian Krone ($ 9.42 billion) in 2009.

Yara implemented several modules in SAP, predominantly for its production operations. They completed their SAP implementation project in 2005. They were in the production system support phase at the time of their participation in this research.

### 1.4.7 OANDO Plc.

Oando Plc, is an integrated energy solutions provider, which comprises a group of companies operating within Nigeria and the African energy sector. The company started business as a Petroleum Marketing enterprise in 1956 under the name ESSO West Africa Incorporated, a subsidiary of Exxon Corporation USA. With the purchase of ESSO's interest by the Federal Government, the company was re-branded "Unipetrol Nigeria Limited" in 1976. After many years of enlarged business scope that saw Unipetrol delve into Supply and Trade as well as the Gas industry, the company bid for and acquired 60% in the equity of Agip Nigeria Plc in 2002. And in 2003, Unipetrol Nigeria merged with Agip Nigeria to form Oando. The company grew over the years and can now boast of a large group comprising of six major subsidiaries: Oando Marketing, Oando Supply & Trading, Oando Gas & Power, Oando Energy Services, Oando Exp. & Production and Oando Refining.

Oando markets a wide range of products including refined petroleum products, premium motor spirit, automotive gas oil, dual purpose kerosene, aviation turbine kerosene, low pour fuel oil, lubricating oils and greases, insecticides, bitumen, chemicals, and liquefied petroleum gas.

In 2004, Oando consolidated its global oil supply and trading businesses to emerge as sub-Saharan Africa's largest, independent and privately-owned oil trading company. Today, Oando imports a significant portion of Nigeria's petroleum product requirements.

With its head office in Lagos, Oando PLC recorded gross earnings of 337 million naira and a profit after tax of 10 million naira as at December 2009.

Oando selected Oracle as its ERP solution, and commenced its implementation in April 2006. In March 2008, Oando announced the completion of its full scale ERP implementation project. This project dubbed 'Project Synergy' served as the executing engine for the organization in deploying world class processes to support its aspirations.

### 1.4.8 Oceanic Bank International

Oceanic Bank International Plc started business in Nigeria on the 12th of June 1990. The bank has its Head office in Abuja, Nigeria, and has been at the forefront of the banking industry in Nigeria by providing comprehensive universal banking services to all its corporate, commercial and individual customers. With over 11,000 employees and 370 business offices, the bank boasts of a network of on-line real-time facilities across its branch offices. Oceanic bank's impressive performance over the years accounts for the quality of its customer portfolio which includes Corporate Organizations, High Net-worth Individuals, the Federal Government and some State Governments.

Oceanic bank has a wide array of unique banking products that include Oceanic Safebox Services, Oceanic ATM-Debit Card, Premium Thrift Account, Vintage Fund, Quality Education Plan, Oceanic Executive Savings Account, Oceanic Pass Pay advance Salary Scheme, Oceanic Quality Life Scheme personal loan scheme, Oceanic Pearl Account zero cot, Oceanic Bank Credit Card, Oceanic Easy Save Account Oceanic t-alert and Oceanic Bank Bureau de Change.

The bank declared a profit after tax of 41 billion Naira at the end of the 2008 financial year. The ERP package selected by Oceanic was SAP. They commenced their SAP implementation in December 2006, and went live with SAP in June 2008.

### 1.4.9 Company C

Company C is a leading business transformation consultancy with over 20 years' experience in designing, implementing and supporting solutions in companies who have selected a packaged ERP solution as a technology platform. They employ over 7,000 employees with SAP and other ERP solution skills and business consulting expertise. Their focus is to improve customers' performance through cost reduction programs, business process improvement, shared service centers, executive coaching and leadership development.

### 1.4.10 Universal Pictures

Universal Pictures (Also known as Universal City Studios or Universal Studios) is a subsidiary of NBC Universal which is a media and entertainment company that develops, produces and markets entertainment, news and information to a global customer base.

Universal Pictures was founded in 1912 by Carl Laemmle as a movies studio which focuses on production. For almost a decade, Universal Pictures has been at the forefront of highly rated movie production with blockbusters like 'A Beautiful Mind', The Bourne Identity' and 'Jurassic Park'. The controlling stake in the company was sold in 2004 by Vivendi Universal to General Electric, parent to NBC. Hence a media super-conglomerate was formed and renamed NBC Universal, while Universal Studios Inc. remained the name of the production subsidiary.

The production studios are located at 100 Universal City Plaza Drive in Universal City, California, USA. The company posted a year-end revenue of 1.2 million dollars in the fiscal year 2008. Universal Studios selected SAP as its ERP solution.

### 1.4.11 Philips

Philips of the Netherlands is a diversified technology company. It is focused on innovation in the areas of healthcare, consumer lifestyle and lighting. The organization is a leader in cardiac care, acute care, and home healthcare energy efficient lighting solutions. In the fourth quarter of 2014, Philips made a sale of $6.5 billion. Their goal is to improve the lives of 3 billion people a year by 2025. Philips has been established for over 120 years. It was established in 1891.

Philips began its SAP implementation journey in 2000, and this was achieved in phases over a number of years. The site-by-site implementation was conducted over all its manufacturing sites and was rolled out globally. The initial implementation included SAP Plant Maintenance and SAP Business Warehouse. The rationale behind the implementation was to establish a set of common interfaces which would enable each site to communicate effectively with the rest of the Philips network.

### 1.4.12 Company L

Company L is a global aerospace, defence and security products manufacturer, employing over 70,000 people worldwide. Their products and services cover air, land and naval forces, electronics, security, and information technology. This company has a presence in the United Kingdom, the Middle East and United States of America. They made sales of over £17 billion in 2013.

The growth and acquisitions of Company L drove it to implement SAP in order to maintain a standardised business process platform. This required business process reengineering across the globe, and it was very challenging. Another key rationale behind implementing an ERP solution was to introduce efficiency into their working practices. The implementation is ongoing and expected to conclude in 2015.

### 1.4.13 Northgate Arinso

Northgate Arinso (NGA) is a global leader in supporting organisations transform their HR operations to deliver more effective and efficient people-critical services. This organisation has a 20 year track record and employ 8,500 people with offices in 35 countries on 5 continents. NGA supports customers in over 100 countries. They have many years of experience in HR consulting, HR outsourcing, and HR technology. NGA are implementation partners for SAP and Oracle. Leading industry organisations such as Gartner have positioned NGA as a market leader.

### 1.4.14 Soft Alliance and Resources

Soft Alliance and Resources is an Oracle implementation partner. They won the Oracle excellence award in 2013. Soft Alliance and Resources are based in the EMEA (Europe, Middle East and Africa) region and specialise in implementing ERP for the public sector. They implement and manage complete end-to-end enterprise software solutions, specific oracle application modules, customer relationship management suites and supply chain management solutions. This organisation is also involved in ERP support and maintenance, application and database host servicing, and project and change management.

## 1.5 The Researcher's Background

The researcher is a senior human resources SAP consultant in the United Kingdom. She has worked in the ERP field for nineteen years. The researcher is highly experienced in analysing, designing and re-engineering business processes for human resources and other functions. In her career, she has acted as both a functional and technical consultant. She has also played the roles of a SAP project manager, change management consultant, and ERP selection specialist. The researcher has lectured in Cranfield University in the area of ERP evaluation and selection. She has worked in a variety of industries including banking, oil and gas, public sector, utilities, and manufacturing to mention a few. Some of the organisations she has worked in are the United Nations, Lloyds Banking Group, Transport for London, SAP, Price Water House Coopers, Accenture, KPMG, CMG, BBC, Airbus, and Kent Police. The researcher is a disciplined individual who is determined to make a positive difference in the ERP industry through research.

## 1.6 Thesis Structure

This thesis comprises ten chapters as illustrated in Figure 1-4. A thorough review of ERP implementation challenges, ERP complexity, software complexity, implementation methodology, costing techniques and modelling techniques, is provided in Chapter 2. The literature review helps to identify the potential need for cost estimation of complexities experienced by ERP project resources. Thereafter, the research gap is analysed. The research methodology which is chosen for this research and the rationale behind the selection are illustrated in Chapter 3. Chapter 4 provides a detailed description of the current ERP implementation challenges and practices faced in a large transport organisation. These challenges are obtained through semi structured interviews and a case study analysis. The case study findings are also discussed in this chapter. Subsequently, the development of the ERP resource complexity costing framework is discussed in detail in Chapter 5 and Chapter 7. This chapter illustrates the various processes for identifying and assessing the complexities in the tool. A presentation of the WBS (Work Breakdown Structure) which is embedded in the tool is provided in Chapter 6. The WBS illustrates the project activities and resources for a typical ERP implementation phase. Chapter 8 presents the framework which is developed for estimating the resource complexity cost of an ERP implementation. The validation process of the ERP resource complexity costing framework is presented in Chapter 9. The research findings and recommendations for future research are summarised in Chapter 10.

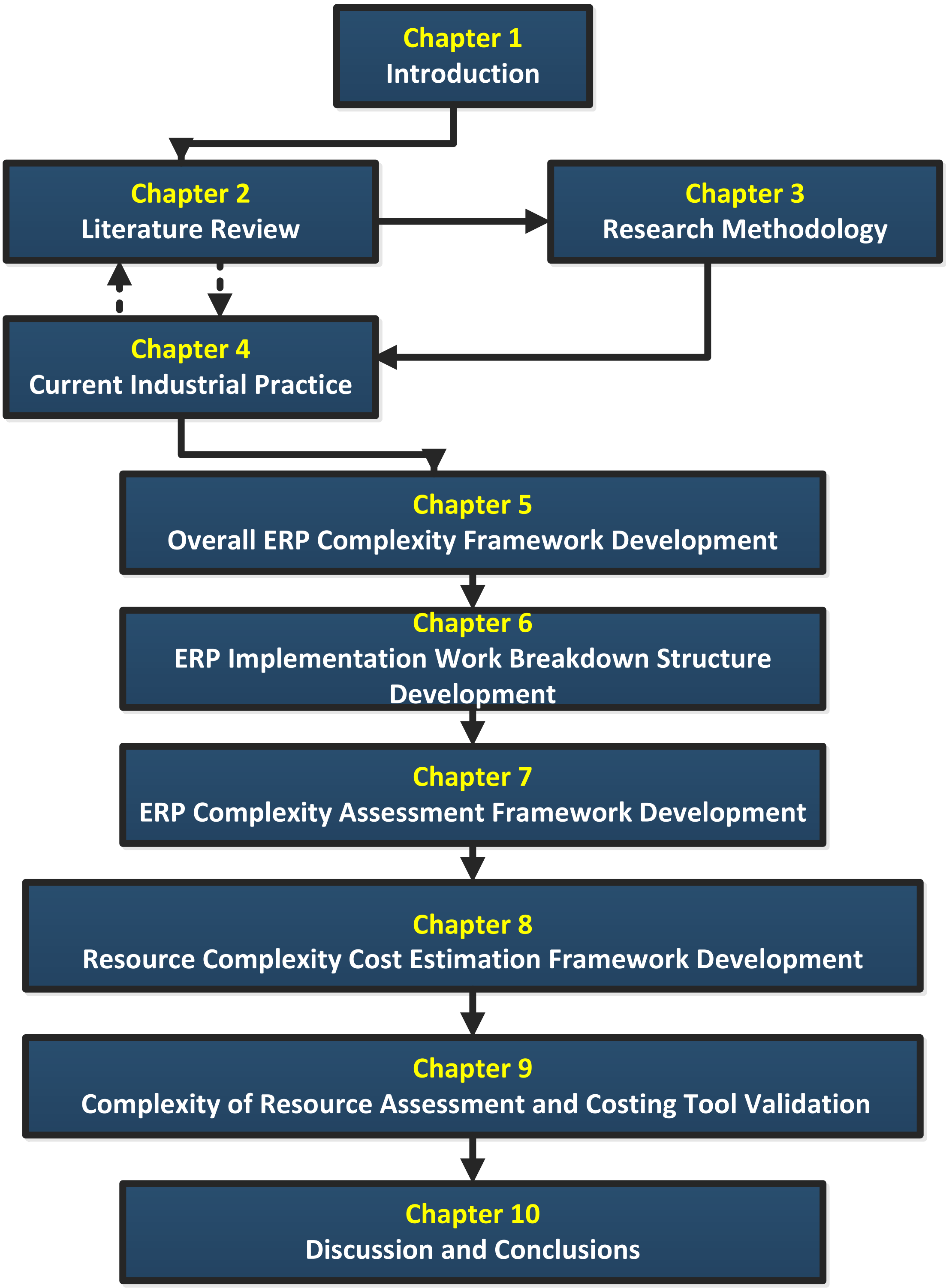



**Figure 1-4:** Thesis Structure

## 1.7 Summary

This chapter aimed to highlight the critical research problem. Initially, the research background was introduced. The background highlighted the ERP implementation challenges, the cost overrun challenges, the existence of complexity in ERP implementations and their impact on cost, the need for quantifying complexity, the experiences of ERP consultants with ERP complexity, and the need to cost the ERP complexities encountered by ERP resources. The research motivation, scope, aim and objectives, collaborating organisations and the thesis structure were presented.

The following chapter presents the literature review and research gap analysis in cost estimation for ERP resource complexity in the ERP implementation stage.

# 2 LITERATURE REVIEW

## 2.1 Introduction

The constantly dynamic global competition which is currently being experienced by organisations has compelled them to adopt enterprise resource planning (ERP) systems in order to gain competitive advantage. However, due to complexity, ERP system implementations have been problematic for over two decades. These complexities have given rise to unforeseen and substantial increases in cost. This experience has caused a myriad of failed implementations. Consequently, a large number of organisations implementing ERP have either cancelled their projects or declared bankruptcy. A significant amount of research has been conducted in this area to establish the causes of these problems. Although complexity is the fundamental cause of ERP failures and cost increases, a comprehensive ERP model, metric and technique for identifying, assessing, measuring and costing complexity have not yet been defined. This creates a difficulty in complexity costing and reduction. Furthermore, considering that project resources are critical to the success of implementations, and the complexities which they experience drive the cost of the project and determine whether or not the project will be a success, it is imperative to cost the complexities from a resource perspective. However, this topic has not been addressed in research. The complexity metrics and costing techniques which are currently presented in research are mostly applicable to software development.

This chapter presents the literature review which combines the research on ERP implementation critical failure factors (CFFs), ERP complexity factors, the impact of ERP resource cost on implementations, complexity metrics for ERP implementations and other software development, ERP costing techniques, uncertainty and risk in ERP costing, and ERP project lifecycle. It fulfils the research objective to investigate the complexity factors inherent in ERP implementations. Figure 2-1 presents a mindmap which illustrates the outline of this chapter.

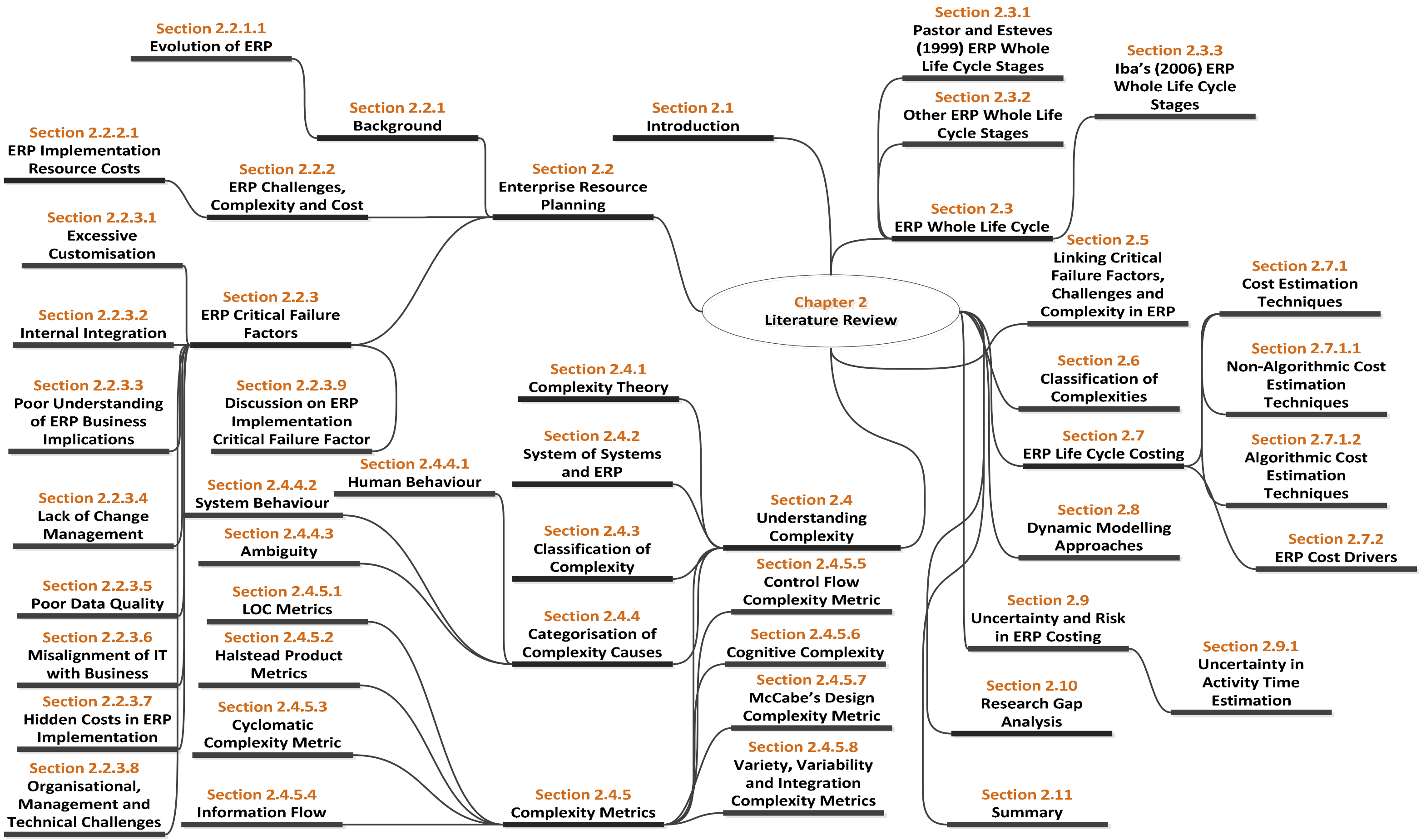



**Figure 2-1*:*** Mindmap for Chapter 2

## 2.2 Enterprise Resource Planning

The adoption and implementation of enterprise resource planning (ERP) systems in organisational contexts have been widely studied at different levels of analysis (Hau *et al.,* 2010). Hau *et al.* (2010) asserts that both the complexities of implementing these systems and the high failure rates in implementations have been widely cited in literature (Hau *et al.,* 2010). This section presents the background of ERP, and highlights its critical failure factors.

### 2.2.1 Background

Information Technology (IT) has advanced markedly in recent years, and plays an important role in corporate globalisation, effectively indirectly intensifying the competition within industries (Chou, *et al.*, 2013). Enterprise resource planning systems are regarded as one of the best information management systems (Chou, *et al.*, 2013; Hau *et al.,* 2010; Matende *et al.,* 2013). As Razmi *et al.* (2009) concedes, today's business environment is dynamic and unpredictable thereby causing companies to face the tremendous challenge of expanding markets and rising customer expectations. Hence it is imperative that ERP systems are able to cope with today's dynamic business environment.

In over a decade, there has been a lot of clamour over enterprise resource planning. ERP has attracted increasing attention from both practitioners across industry, and researchers (Momoh *et al*., 2010; Momoh *et al*., 2007). Boonstra (2006), Chou *et al.* (2013), Hau *et al.* (2010), Matende *et al.* (2013), Rao (2000a, b) and Rajnoha *et al.* (2014) define ERP as a software solution which integrates the various functional spheres and streamlines the business processes in an organisation. ERP is a customisable standard application software (Pandey *et al.,* 2009) which promises the seamless integration of all the information flowing through a company – financial and accounting information, human resource information, supply chain information and customer information (Davenport, 1998; Hallikainen *et al.,* 2006; Tarn *et al.,* 2002; Holland *et al.,* 1999). Corkindale *et al.* (2014) and Rao (2000a, b) define

ERP as a link through the entire supply chain. It is aimed at best industry and management practices (Rao, 2000a, b; Pandey, 2009) for providing the right product at the right place, at the right time, at least cost (Rao, 2000a, b). The introduction of ERP systems within an organisation is generally considered a strategic initiative, and aligned with long-term business benefits (Corkindale *et al.,* 2014). The information provided by ERP systems is used to support strategy, operations, management analysis, and decision-making functions in an organisation (Matende *et al.,* 2013; Corkindale *et al.,* 2014). Kogetsidis *et al.* (2008) implies that these systems improve the interaction between organisations, and their customers and suppliers. Therefore, due to their effect on so many aspects of an organisation's internal and external operations, the successful deployment and use of ERP solutions are critical to organisational performance and survival (Boonstra, 2006).

Kogetsidis *et al*. (2008), Themistocleus *et al.* (2001) and Chou *et al.* (2013) specify the implicit benefits to be:

- increased transparency of business information
- improved workflow
- rapid responses to client needs
- efficient information sharing
- business and operational efficiency
- increased global competitiveness
- reduced development risk

#### 2.2.1.1 Evolution of ERP

ERP is used in several industries and sectors to enable competitive advantage and business integration. Although ERP found its roots in manufacturing, ERP solutions are used by other capital-intensive industries such as construction, aerospace and defence (Chung *et* al., 2000; Momoh *et al*., 2010). The evolution of ERP systems began with material requirements planning (MRP) (Chou *et al.,* 2013; Pandey *et al.,* 2009). MRP assisted companies in the 1960s to compete by improving quality and workflow management, and automating manual procedures for planning and controlling production schedules (Chou *et al.,* 2013; Swan *et al.,* 1999). MRP soon evolved into manufacturing resource planning (MRP II), which simply integrates manufacturing resources. According to Chou *et al.* (2013), although customers had diverse real-time requests which were crucial to operational success, intense competition shortened product lifecycles. However, MRP II was not equipped to manage these requests. Hence ERP was introduced, thereby replacing MRP II (Chou *et al.,* 2013; Parry, 2005; Pandey *et al.,* 2009; Swan *et al.,* 1999). The key advantages which ERP has over MRP II is that it responds to dynamic environmental changes and actual needs, and it is applicable to supply chain management (SCM), customer relationship management (CRM), and data warehousing, in which the ERP system is embedded to increase its comprehensiveness (Chou *et al.,* 2013). However, despite the advent of ERP, there is a lot of uncertainty in manufacturing processes which affects the competition in manufacturing (Pandey *et al.,* 2009).

### 2.2.2 ERP Challenges, Complexity and Cost

The continual pace of change in organisations and their environment has resulted in complex technical organisational, cultural and political issues that have made the ERP integration process a very challenging task (Momoh *et al.,* 2010; Huang *et al.,* 2003). In support of this view, Chen *et al.* (2009) caution that an ERP system is a complex network composed of various business processes. Implementing ERP systems is a costly and complex undertaking, and many ERP system implementations result in failure (Chen *et al.,* 2006; Corkindale *et al.,* 2014; Hau *et al.*, 2010; Momoh *et al.,* 2010; Aitken, 2002; Snider *et al.,* 2009). According to Vogt (2002), the tremendous complexity of ERP systems makes them prone to glitches and low performance, difficult to maintain, and nightmarish to implement. Vogt (2002) also advises that one of the reasons for ERP complexity is that the system can run virtually every aspect of any business, thereby causing a difficulty in implementation, set-up and maintenance. Rao (2000) estimates that 96.4% of ERP implementations fail, whereas Thermistocleous (2001) reports that 70% of ERP implementations do not achieve their estimated benefits.

ERP implementations are notorious for taking a longer time and costing more money than is projected (Abdullah *et al.,* 2014; Davenport, 1998; Reda, 1998; Jacob, 1999; Mabert *et al*., 2000; Ehie *et al.,* 2005; Tarn *et al.,* 2002). Some implementations cost more than double the initial project estimate (Montalbano, 2010; Babcock, 2011; Kanaracus, 2011). Hence, in almost two decades, organisations have struggled to implement ERP effectively, despite all of the benefits it offers (Momoh *et al.*, 2010). This is not always because ERP solutions are poorly designed, but because these systems are complex, and therefore fraught with challenges. This cost and time overrun has led a large number of companies to either cancel their ERP implementation projects or declare bankruptcy (Momoh *et al.,* 2010). ERP implementation costs include software, training, hardware and consulting costs (Snider *et al.,* 2009). The costs transcend just the software. Ehie *et al.* (2005) estimate the system-based cost of an ERP implementation to average 40% of the total cost, whilst the remaining 60% of the cost is injected into training and professional services. Implementation costs can run as high as 3% of an organisation's total revenue (Ehie *et al.,* 2005). An ERP system has an average total cost of ownership (TOC) of $15 million (Tarn *et al.,* 2002).

#### 2.2.2.1 ERP Implementation External Resource Costs

One of the most critical requirements for a successful ERP project is to deploy knowledgeable internal resources to the project. Teams are an effective structure for organising information systems (IS) projects (Hsu, 2011). Hsu *et al.* (2011) provide a simple definition of a team as a group of people working on interrelated tasks to achieve a common goal. However, due to the complexity of ERP systems, organisations do not have the internal expertise required to implement these solutions (Tarn *et al,* 2002). It is for this reason that ERP adopters frequently hire consultants who are external resources with expertise in the ERP module, to assist the organisation in implementing the ERP solution. External consultants, who provide technical and business expertise, reduce learning burden (Chen and Wang*,* 2006). Their expertise enables clients to configure an appropriate ERP system. Furthermore, their expertise helps to train users to fully exploit the technology. According to Hsu *et al*. (2011), the implementation of information systems projects requires the communication of knowledge and expertise from different domains to effectively diagnose the problems and design the solutions. However, these consultants have to be paid and they are costly. Stefanou (2001) emphasises that consultants' fees can be a very heavy burden on the budget for supportive activities. Vogt (2002) and Stefanou (2001) suggest that consulting cost is one of the hidden costs in ERP implementations, and this may prove to be a barrier to successful implementations. Unanticipated difficulties are always encountered on ERP projects, and can sometimes lead to unexpected high expenses; therefore, even though the cost of the ERP software solution is provided in advance, the consulting firm's effort is subject to change, and so is its bill (Vogt, 2002). Furthermore, Stefanou (2001) stipulates that it is very common to underestimate the time it takes to implement an ERP system. Snider *et al.* (2009) imply that even though project resource shortage might hinder project success, an ERP adopter may face challenges in paying for consulting.

### 2.2.3 ERP Critical Failure Factors

A study was conducted on the causes of ERP failures in order to understand the challenges and complexities facing ERP adopters. These challenges are presented as critical failure factors in Figure 2-2. Umble *et al.* (2003) define failure as an implementation that does not achieve the return on investment (ROI) identified in the project approval phase, and posit that failure rates are in the range of 60% to 90% of ERP implementations.

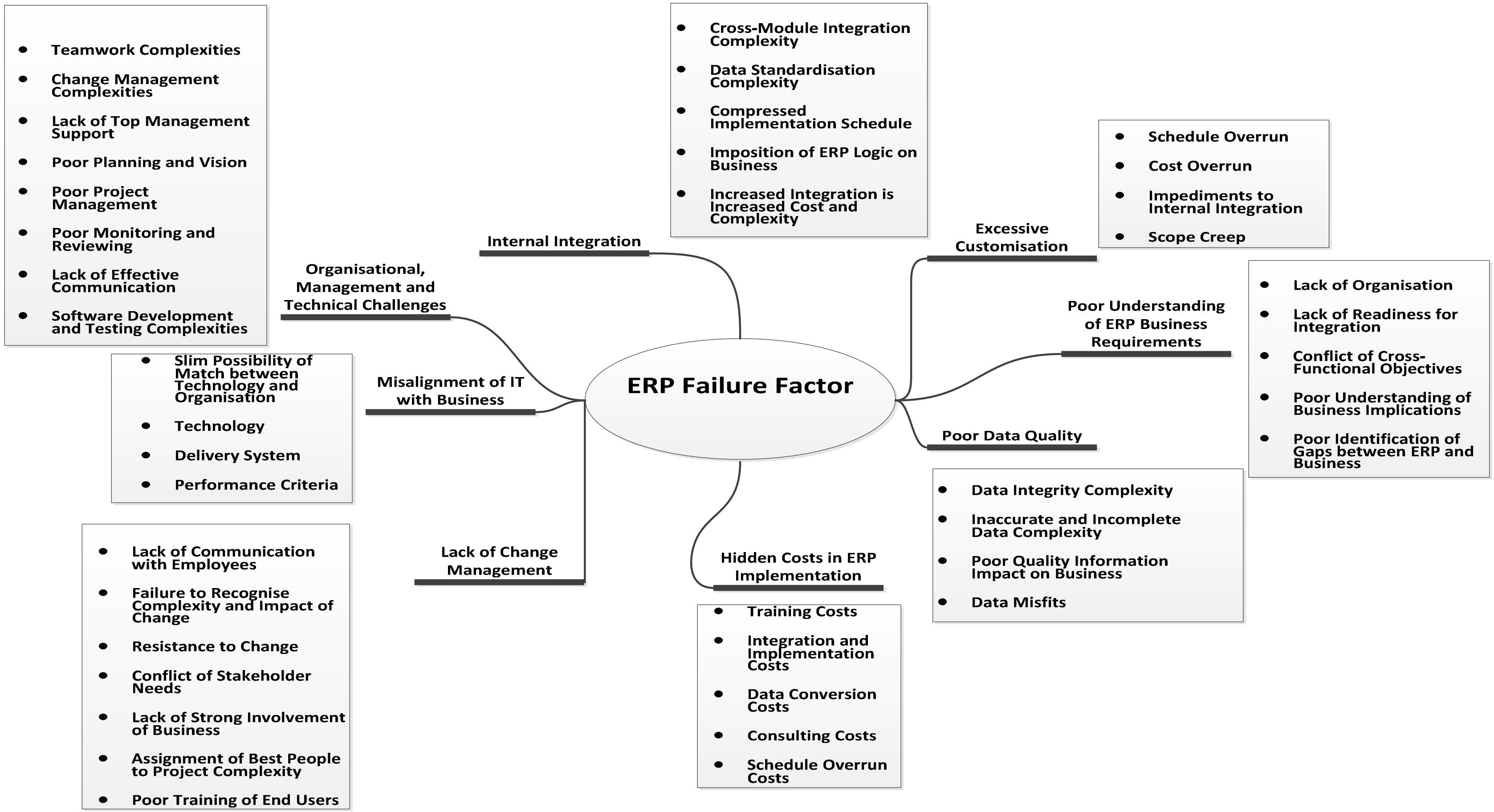



**Figure 2-2**: ERP Critical Failure Factors

#### 2.2.3.1 Excessive Customisation

Law *et al.* (2010) define customisation as modifications made to the native features of an ERP product which may include modifications to user interfaces, reports, program codes, messages, and additions of bolt-on logic to the native system. Hence, care must be taken particularly when modifying the system, as if a company alters an ERP package, it can impede the internal integration of ERP modules (Janols *et al.,* 2013; Faasen *et al.,* 2013; Khanna *et al.,* 2012; Huang *et al.,* 2012; Jharkharia, 2011; Snider *et al.,* 2009; Thermistocleous, 2001; Shehab *et al*., 2004; McAdam *et al*., 2005; Chung *et* al. 2000). Aloini et al. (2007) stress that if not adequately planned, personalisation and adaptation of tools may cause trouble. Shehab *et* al. (2004), Davenport (1998) and Sumner (1999) also stress that organisations face numerous problems when customising ERP packages.

#### 2.2.3.2 Internal Integration

ERP implementations are challenging due to cross-module integration, data standardisation, adoption of the underlying business model, compressed implementation schedule and the involvement of a large number of stakeholders (Tarn *et al.,* 2002; Soh *et al.,* 2000). Davenport (1998) discusses the fact that ERP solutions are modular and in light of integration, the greater the modules selected, the greater the integration benefits, but also, the greater the costs, risks and changes involved. Aloini et al. (2007) caution that the number of implementation modules increases project complexity. Youngberg *et al.* (2009) reveal that for businesses, the ever-expanding amount of information that has to be managed leads to an increase in system integration and complexity.

#### 2.2.3.3 Poor Understanding of ERP Business Implications

A number of companies that implement ERP do not realise the full benefits that the solution offers because most organisations are not organised in the correct fashion to achieve the benefits (Yusuf et al., 2004; Ehie *et al.*, 2005). Langenwalter (2000) stipulates that many companies that attempt to implement ERP solutions run into difficulty because the organisation is not ready for integration and the various departments within it have their own agendas and objectives that conflict with each other.

The critical challenge in ERP implementation has been to first identify the gaps between the ERP generic functionality and the specific organisational requirements (Soh et al., 2000). According to Davenport (1998), even though some of the causes of ERP failures lie with technical challenges, these are not the main reason enterprise systems fail. Davenport (1998) stresses that the biggest challenges are business problems in the sense that companies fail to reconcile the technological imperatives of the enterprise system with the business needs of the enterprise. Thus, if a company rushes to install an enterprise system without first understanding the business implications, the dream of integration can quickly turn into a nightmare (Davenport, 1998).

#### 2.2.3.4 Lack of Change Management

Almajed *et al.* (2013), McAdam *et al.* (2005) and Aloini *et al.* (2007) report that a lack of change management is one of the major causes of implementation failures. Hence, it is essential to manage successful ERP implementations as a program of wide-ranging organisational change initiatives rather than as a software installation effort (Yusuf et al., 2004). This approach involves intertwining technology, task, people, structure and culture. Consequently, the implementation process is transparent and enables the easy identification, avoidance and mitigation of risks. Additionally, as all the relevant areas are addressed as part of the implementation, resistance to change is reduced and in some cases, eliminated. Thus, organisational resistance to change is identified as a critical success factor (Hong *et al.*, 2002), and cultural readiness for an ERP implementation must be carefully planned (McAdam *et al.*, 2005).

#### 2.2.3.5 Poor Data Quality

The integrity of the data used to operate and make decisions about a business affects the relative efficiency of operations and quality of decisions made; protecting data integrity is a challenging task (Vosburg *et al.*, 2001). One of the issues in information management is getting the right information to the right person at the right time and in a usable form (Youngberg *et al*., 2009). Information research has demonstrated that inaccurate and incomplete data may severely affect the competitive success of an organisation (Gulkvist, 2013; Hongjiang et al., 2002). Poor quality information can have significant social and business impacts (Strong *et al*., 1997). Poor data quality at the operational level increases operational cost because time and other resources are spent detecting and correcting errors (Glowalla *et al.,* 2014; Park *et al.*, 2005). Alshawi et al. (2004) argue that data accuracy is an issue in the sense that if the data that goes into a system is not accurate or immediately accessible, the whole system becomes suspect.

#### 2.2.3.6 Misalignment of IT with Business

Owing to the rapidly changing business environment, ERP implementation is seldom a simple matter of realising a plan; instead, it is often a dynamic process of mutual adaptation between IT and the surrounding environment (Ho *et al*., 2004). Given the slim possibility of achieving a perfect match between technology and organisation, misalignment can occur which can be rectified through technological measures, organisational measures or a combination of both. Ho *et al.* (2004) developed the Leonard-Barton framework which addresses critical issues according to the dimension into which they fall. There are three dimensions in this framework; technology, delivery system and performance criteria. The technology dimension issues are; adequacy for specification, user's maturity for the application of new technology, and evaluation and integration for legacy system. As regards the delivery system, its issues are: role of the MIS department in organisation, process adaptation, harmonious implementation, system establishment, project management, employee education and training, external partner support and internal staff involvement. Finally, the issue for performance criteria is performance evaluation. Ho et al. (2004) advise that during implementation, all three dimensions influence each other. A successful implementation will benefit from the application of all three dimensions, and not a single one.

#### 2.2.3.7 Hidden Costs in ERP Implementation

Yusuf *et al*. (2004) reported that an ERP system has problems of uncertainty in acquisition and hidden costs in implementation. Tarn *et al.* (2002) argue that cost is a critical part of an ERP implementation for both large and small businesses alike. Companies that install ERP solutions may underestimate cost that is hidden (Tarn *et al.,* 2002). An ERP system has an average total cost of ownership of $15 million but rewards the business with an average negative net present value of $1.5 million (Momoh *et al.* 2010; Wheatley, 2000; Tarn *et al, 2002*). Training costs, integration and implementation costs, data conversion cost, and consulting costs are identified as hidden costs by Momoh *et al.* (2010), Tarn *et al.* (2002), Slater (1998) and Soh *et al*. (2000). Training is the most underrated hidden cost, as the cost to train an entire staff on a new system is enormous and often taken for granted. As for integration and implementation costs, they are often overlooked. In terms of the cost of data conversion, it is hidden as poor data quality may lead to indirect costs (Glowalla *et al.,* 2014). Furthermore, companies often do not recognise the cost associated with transferring data from the old system to the new package. Included in the cost of data conversion is the need to modify the data to fit into the new system and the need to hire professionals can send this type of cost higher. High consulting cost becomes inevitable as a consequence of many companies not budgeting consulting fees in a proper and structured manner.

#### 2.2.3.8 Organisational, Management and Technical Challenges

McAdam *et al*. (2005) reported that key organisational issues in an ERP implementation are teamwork, change management, top management support, plan and vision, business process management and development, project management, monitoring and review, effective communication, software development and testing, the role of the project champion and appropriate business and IT legacy systems. The results of their study indicate that the complex organisational change issues must be comprehensively addressed. These issues cannot be resolved solely with technical solutions. McAdam *et al.* (2005) emphasise that other key implementation issues are poorly defined roles and responsibilities, weak management capability, poor management behaviours, and limited training. To support these results, Huang *et al.* (2003, 2004) suggest that in addition to developing the technical aspects of ERP, more effort is required in understanding the more complex organisational issues involved.

#### 2.2.3.9 Discussion on ERP Implementation Critical Failure Factors

ERP critical failure factors (CFFs) have been discussed in literature review by several authors. The citations are outlined in Table 2-1.

In the literature review conducted on ERP critical failure factors, a total of 87 citations were made by the authors presented in Table 2-1. This illustrates that there is a high level of awareness of the CFFs in research. In Figure 2-3, the contribution of each critical failure factor (CFF) in relation to the total citation is illustrated.

The challenge with the highest contribution to implementation failure based on this literature review is excessive customisation at 27%, as illustrated in Figure 2-3. This is an indication that most of the failures encountered by ERP adopting organisations, is caused by high levels of customisation.

**Table 2-1:** ERP Critical Failure Factor Citation

| **Critical Failure Factors** | **Author** | **Number of Citations** |
|---|---|---|
| Excessive Customisation | Shehab et *al*. (2004), Momoh *et al.* (2010), Law *et al.* (2010), Janols *et al.* (2013), Jharkharia (2011), Faasen *et al*. (2013), Khanna *et al.* (2012), Huang *et al.* (2012), Wheatley (2000), Chung *et al.* (2000), Ehie *et al.* (2005), Sumner (1999), Rao (2000a), Rao (2000b), Kogetsidis *et al.* (2008), Verma (2007), Aloini *et al.* (2007), Helo (2008), Snider *et al.* (2009), Vogt (2002), Thermistocleus (2001), McAdam *et al.* (2005), Davenport (1998) | 23 |
| Dilemma of Internal Integration | Youngberg *et al.* (2009), Momoh *et al.* (2010), Themistocleus *et al.* (2001a), Shehab *et al*. (2004), Davenport (1998), McAdam *et al.* (2005), Chung *et al.* (2000), Soh et al. (2000), Aloini et al. (2007), Tarn *et al.* (2002), Ash *et al.* (2003), | 16 |
| Poor Understanding of Business Implications and Requirements | Kogetsidis et *al*. (2008), Davenport (1998), Momoh *et al.* (2010), Langenwalter (2000), Yusuf *et al.* (2004), Ehie *et al.* (2005), Soh *et al.* (2000) | 7 |
| Lack of Change Management | McAdam *et al.* (2005), Almajed *et al.* (2013), Momoh *et al.* (2010), Yusuf et al. (2004), Hong *et al.* (2002), Markus *et al.* (2000), Sumner (1999), Aloini et *al*. (2007), Kamhawi (2008) | 14 |
| Poor Data Quality | Momoh *et al.* (2010), Youngberg et *al*. (2009), Glowalla *et al.* (2014), Gullkvist (2013), Vosburg *et al.* (2001), Strong et *al*. (1997), Hongjiang et *al*. (2002), Soh et *al*. (2000), Alshawi et *al*. (2004), Park *et al.* (2005) | 14 |
| Misalignment of IT with the Business | Ho et *al*. (2004),<br>Momoh *et al.* (2010) | 2 |
| Hidden Costs in ERP Implementation | Yusuf et *al*. (2004), Wheatley (2000), Momoh *et al.* (2010), Glowalla *et al.* (2014), Tarn *et al.* (2002), Slater (1998), Soh *et al.* (2000) | 7 |
| Organisational, Management and Technical Challenges | McAdam *et al.* (2005), Huang *et al.* (2003), Momoh *et al.* (2010), Huang et *al*. (2004) | 4 |

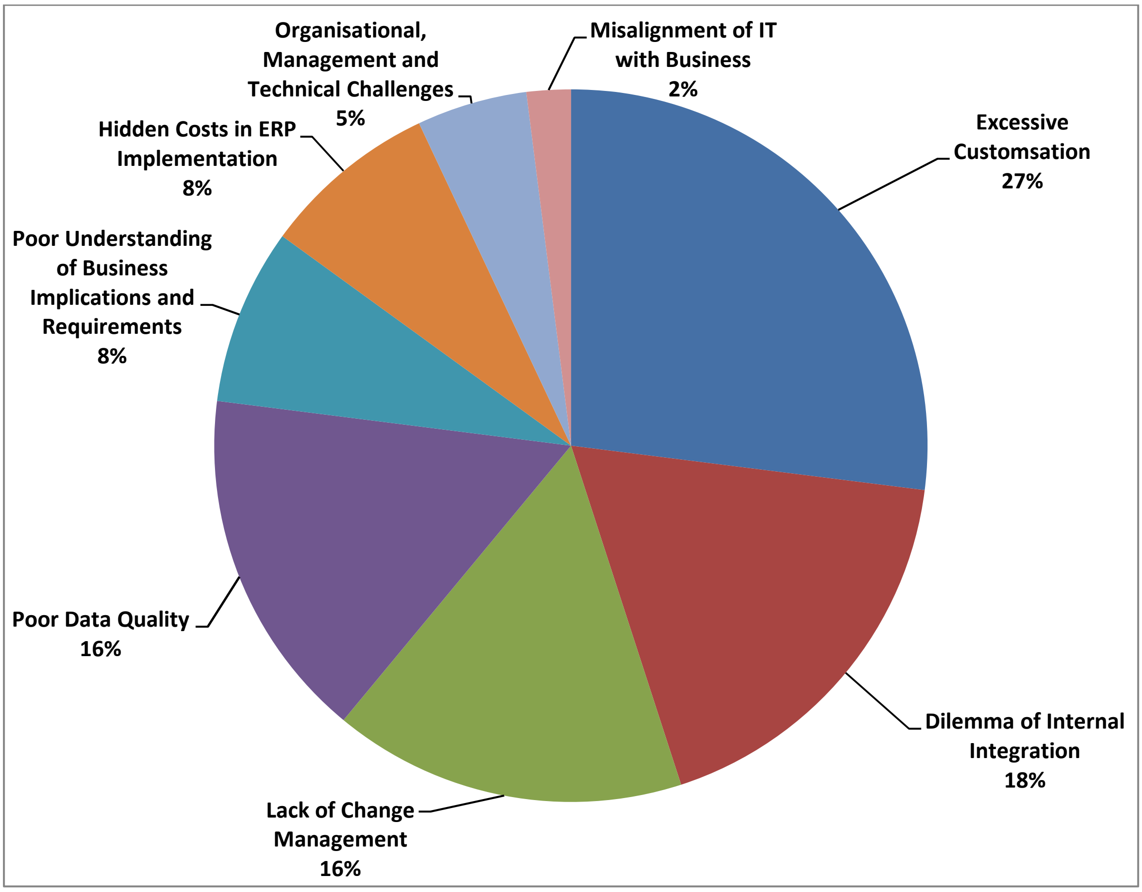



**Figure 2-3:** Contribution of CFF in Citation

The next highest contribution to failure is dilemma of internal integration at 18%, which illustrates that most organisations implementing ERP struggle to adopt the standard integration offered by the system. Poor data quality and lack of change management account for 16% of ERP implementation failures as cited by the authors in Table 2-1. A poor understanding of business implications and requirements, and hidden costs in ERP implementation constitute 8% of the failures cited in literature. This is an indication of two factors; (1) although hidden costs are quite crucial in implementations, they do not contribute on a high scale to failure, and (2) a poor understanding of business implications and requirements is experienced on a lower scale than most other failures which have been reported in this literature review. The two lowest contributions to

ERP failure are misalignment of IT with the business at 2% and organisational, management and technical challenges at 50%. The trend of ERP implementation failure based on the citations in this literature review is depicted in Figure 2-4.

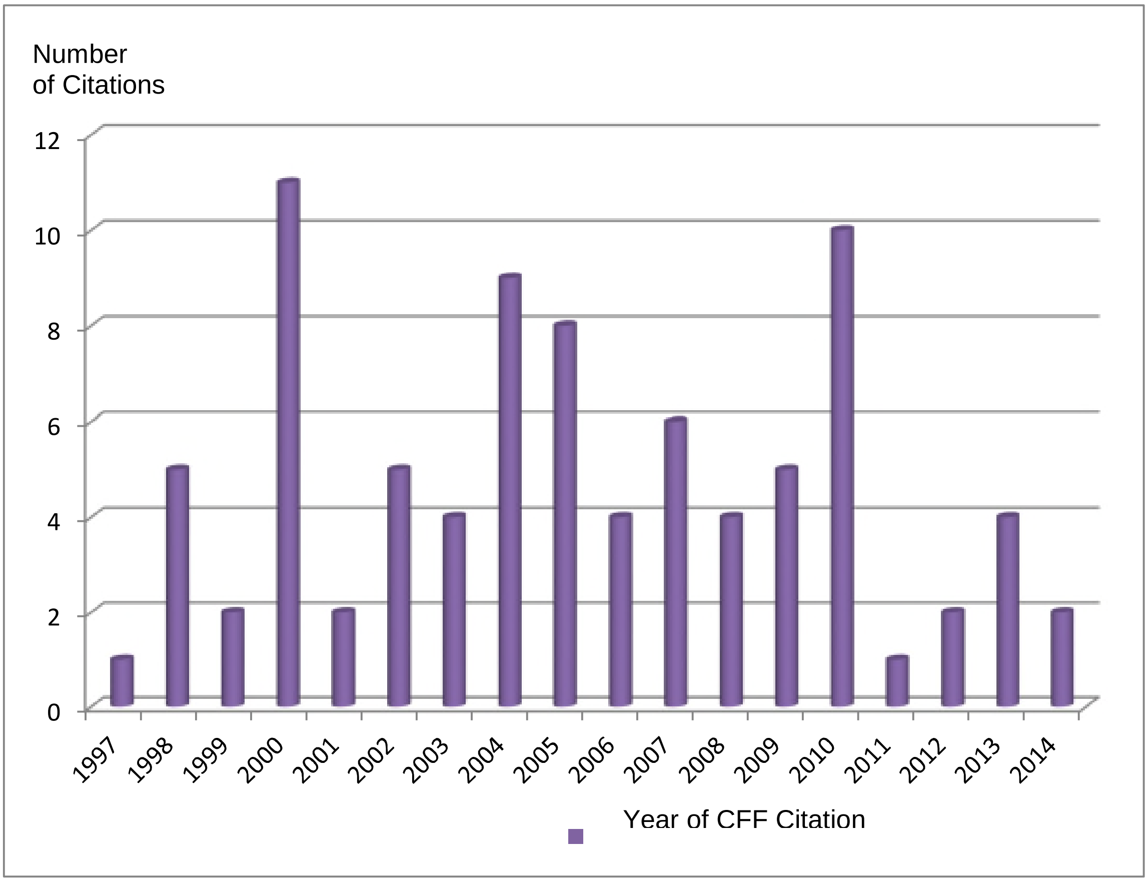



**Figure 2-4:** ERP Implementation Failure Trend

The ERP critical failure factors which have been studied in this literature review are cited between 1997 and 2014, as illustrated in Figure 2-4. ERP implementation failures were relatively mentioned in 1997, but there was a significant amount of research on these failures in 1998. However, in 1999, research on CFFs had reduced again, but increased immensely in 2000. This substantial increase may also have been impacted by the Year 2000 bug which was affecting ERP implementations (new and old). The problems reduced again in 2001, increased slightly in 2002 and reduced on a small scale in 2003. There was a drastic increase again in 2004 and a fluctuation in research on ERP failures from this time to 2010, when Momoh *et al.* (2010) conducted a comprehensive review on ERP critical failure factors. This caused the increase in citations in 2010 based on this literature review. Between 2011 and 2014, there has been a decrease in research on ERP implementation failures, albeit with slight fluctuations within these periods. The researcher believes that the reason for less mention of ERP failures may have been caused by a shift in focus to ERP cloud computing due to its advent.

## 2.3 ERP Whole Life Cycle

ERP systems are not projects that someday will end, but rather, they are a way of life (Pastor *et al.*, 1999). The pre-implementation, implementation and post-implementation stages continue throughout the lifetime of the ERP as it evolves with the organization (Chang, 2004).

This section is based on a study of ERP project whole life cycle (WLC) stages. The rationale behind this study is to enable the identification of ERP complexities in ERP project activities within the implementation stage. This mapping allows ERP project resources to be identified for complexity costing based on the project activities to which the resources are allocated.

### 2.3.1 Pastor and Esteves (1999) ERP Whole Life Cycle Stages

Pastor *et al*. (1999) describe six stages of an ERP whole life cycle; adoption decision, acquisition, implementation, use and maintenance, evolution and retirement. These stages are illustrated in Figure 2-5.

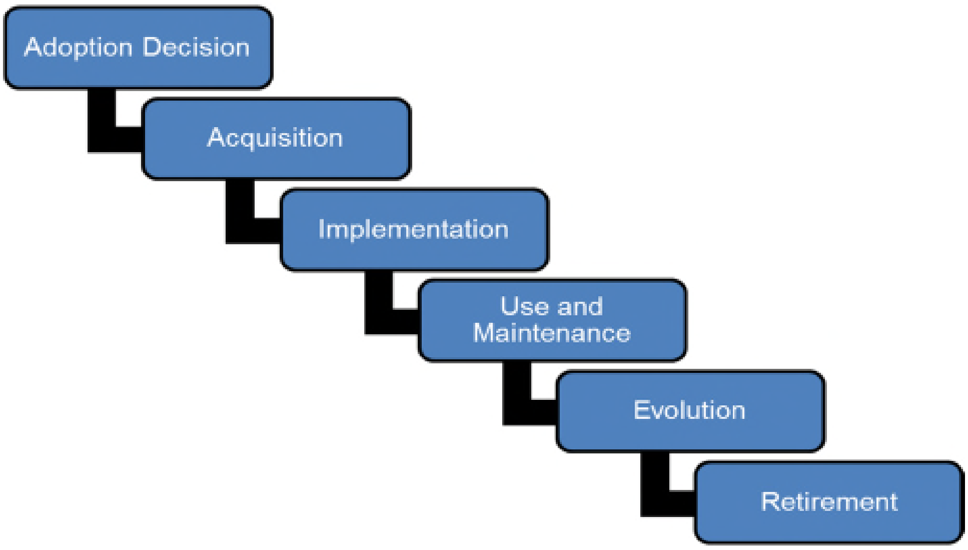



**Figure 2-5:** ERP Project Whole Lifecycle Stages

**Adoption Decision**: this stage includes the definition of system requirements, its goals and benefits, and an analysis of the impact of adoption at a business and organizational level (Pastor *et al.,* 1999).

**Acquisition**: this phase consists of the product selection that best fits the requirements of the organization (Pastor *et al.,* 1999)..

**Implementation**: this phase consists of the customization or parameterization and adaptation of the ERP package acquired according to the needs of the organization (Pastor *et al.,* 1999).

**Use and maintenance**: once a system is implemented, it must be maintained, because malfunctions have to be corrected, special optimization requests have to be met, and general systems improvement have to be made (Pastor *et al.,* 1999).

**Evolution**: this phase corresponds to the integration of more capabilities into the ERP system, providing new benefits, such as advanced planning and scheduling, and supply-chain management (Pastor *et al.,* 1999).

**Retirement**: this phase corresponds to the stage when with the appearance of new technologies or the inadequacy of the ERP systems or approach to the business needs, managers decide if they will substitute the ERP software with other information system approach more adequate to the organizational needs of the moment (Pastor *et al.,* 1999).

### 2.3.2 Other ERP Whole Life Cycle Stages

In support of the ERP WLC stages defined by Pastor *et al.* (1999) above, Ross (1999) describes five stages; (i) The Approach which is the design stage, (ii) The Dive which is the implementation stage, (iii) Resurfacing which is the stabilization stage, (iv) Swimming which is the continuous improvement stage, and (v) Transformation which is the stage that would involve changing organizational boundaries, particularly with regard to systems.

Somers *et al*. (2004) have also described a six-stage ERP project WLC. The stages are; (i) initiation, (ii) adoption, (iii) adaptation, (iv) acceptance, (v) routinisation, and (vi) infusion.

ERP implementation success is improved when the life cycle phases are combined with project “threads” (Wagner and Antonucci, 2004). Wagner and Antonucci (2004) define a five-stage ERP project life cycle with threads in Figure 2-6.

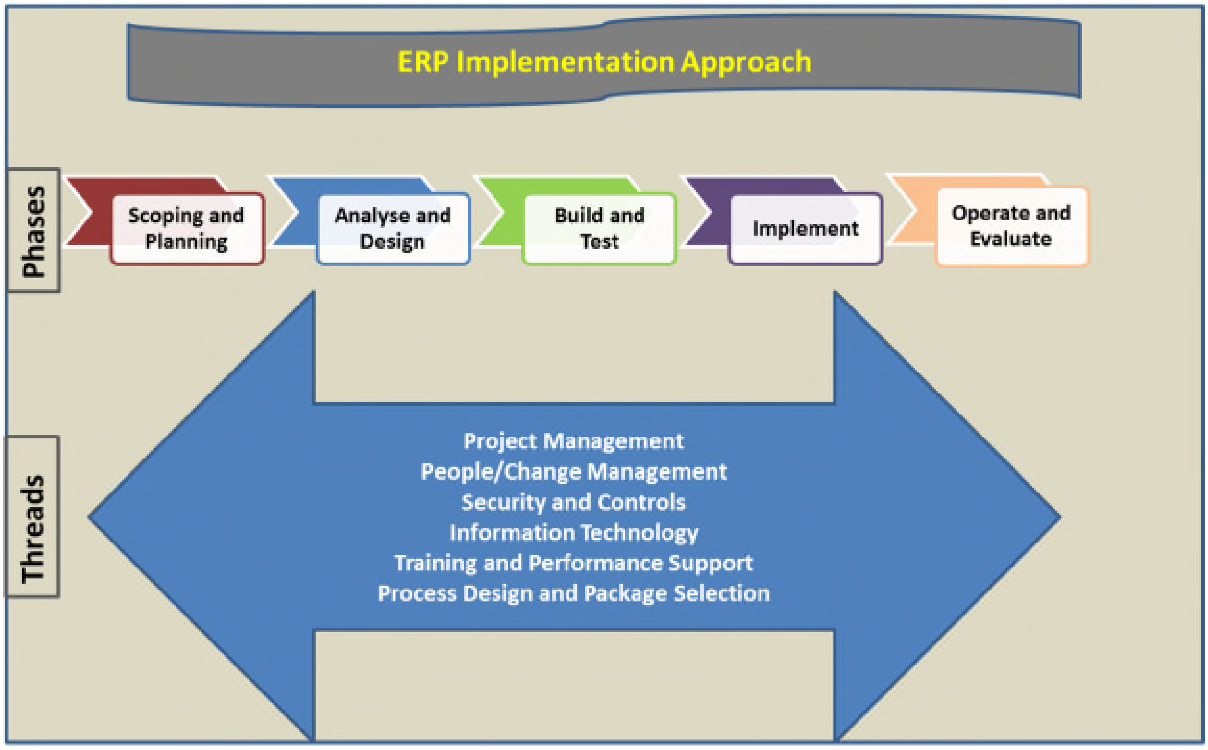



**Figure 2-6:** Generalised ERP Implementation Approach

Wagner and Antonucci (2004) discuss five implementation phases in an ERP project life cycle; (1) scoping and planning, (2) analyse and design which involves developing a project blueprint and establishing basic requirements, (3) build and test which involves redesigning and streamlining business processes, and testing the system to ensure integrated functionality, (4) implement which involves implementing the system in phases, and (5) operate and evaluate. The first two phases are the initial phases of an ERP implementation project, and the last three phases constitute the core implementation (Wagner and Antonucci, 2004). Wagner and Antonucci (2004) define six threads across all the project phases; (1) project management which focuses on the organisation and management of the entire project, (2) people and change management which involves the ability to manage change throughout an ERP implementation and is critical to its success, (3) security and controls which ensures the process integrity by developing security infrastructure that includes policies, procedures, application security, and audit control, (4) information technology which involves the assessment, design, development, implementation, and testing the technical infrastructure, (5) training and performance support which includes aligning the project with the business strategy, performing a gap analysis, developing overall testing and documentation, procedures, and process implementation and monitoring, and (6) process design and package implementation which involves defining the ERP system from a business perspective in order to make a sound and attractive business case.

Tchokogue *et al.* (2005) define five major implementation phases as scoping and planning, visioning and targeting, process redesign, configuration, and testing and delivery. This ERP project life cycle is known as Fast-Track 4 SAP methodology.

### 2.3.3 Iba's (2006) ERP Whole Life Cycle Stages

The final ERP whole life cycle studied was based on the thesis of Iba (2006) and a paper written by Ehie *et al*. (2004). The stages of the combined ERP whole life cycle are depicted in Figure 2-7, and Figure 2-8 illustrates the activities in the implementation stage.

The implementation phases highlighted in Figure 2-7 under stage 3, are similar to those in the SAP implementation methodology which was defined by the software vendor SAP. This methodology is known as ASAP which was introduced with the goal of speeding up SAP projects (Momoh *et al.,* 2008a, b; Esteves *et al.,* 2003). ASAP is a structured implementation approach which can enable managers to achieve a faster implementation with quicker user acceptance, well-defined roadmaps, and efficient documentation at various phases.

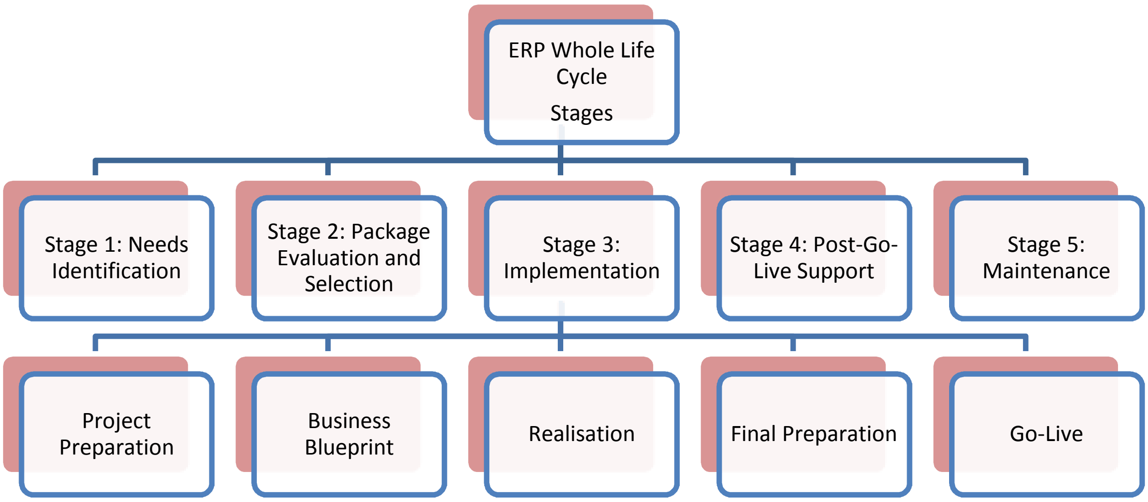



**Figure 2-7:** Stages of an ERP Whole Life Cycle (Adopted from Iba, 2006)

As illustrated in Figure 2-8, each implementation phase is composed of a group of work packages which are structured in activities, with each activity composing of a group of tasks (Momoh *et al.,* 2008a, b; Esteves *et al.,* 2003). For each task, a definition, a set of procedures, results and roles are provided in the ASAP methodology documentation (Momoh *et al.,* 2008a, b; Esteves *et al.,* 2003).

Iba (2006) developed a whole life cycle costing framework based on the life cycle stages in Figure 2-7, and the interviews and literature review which she conducted on whole life cycle costing techniques. As her work is closely related to this research, the researcher will use the implementation methodology in Figure 2-8, as the basis for the ERP resource complexity costing framework that will be developed in this research. The rationale behind this decision is that the implementation stage entails more activities than the other stages in the whole life cycle, as illustrated in Figure 2-8. As highlighted in Section 1.1.2, complexity increases with activity. This indicates that most of the complexity in an ERP whole life cycle resides in the implementation activities. It was also asserted in Section 1.1.1 that complexity drives cost. Therefore, the implementation stage is the most costly one in the project WLC. Furthermore, this stage is where the ERP solution is realised, which makes it the most important stage. Hence if the implementation fails, the whole project life cycle has failed. It is based on these reasons that the implementation stage is the focus of this research. In summary, whist there are many ERP development life cycles practiced today, there is a general agreement on the typical phases of this life cycle for ERP implementations (Wagner and Antonucci, 2004).

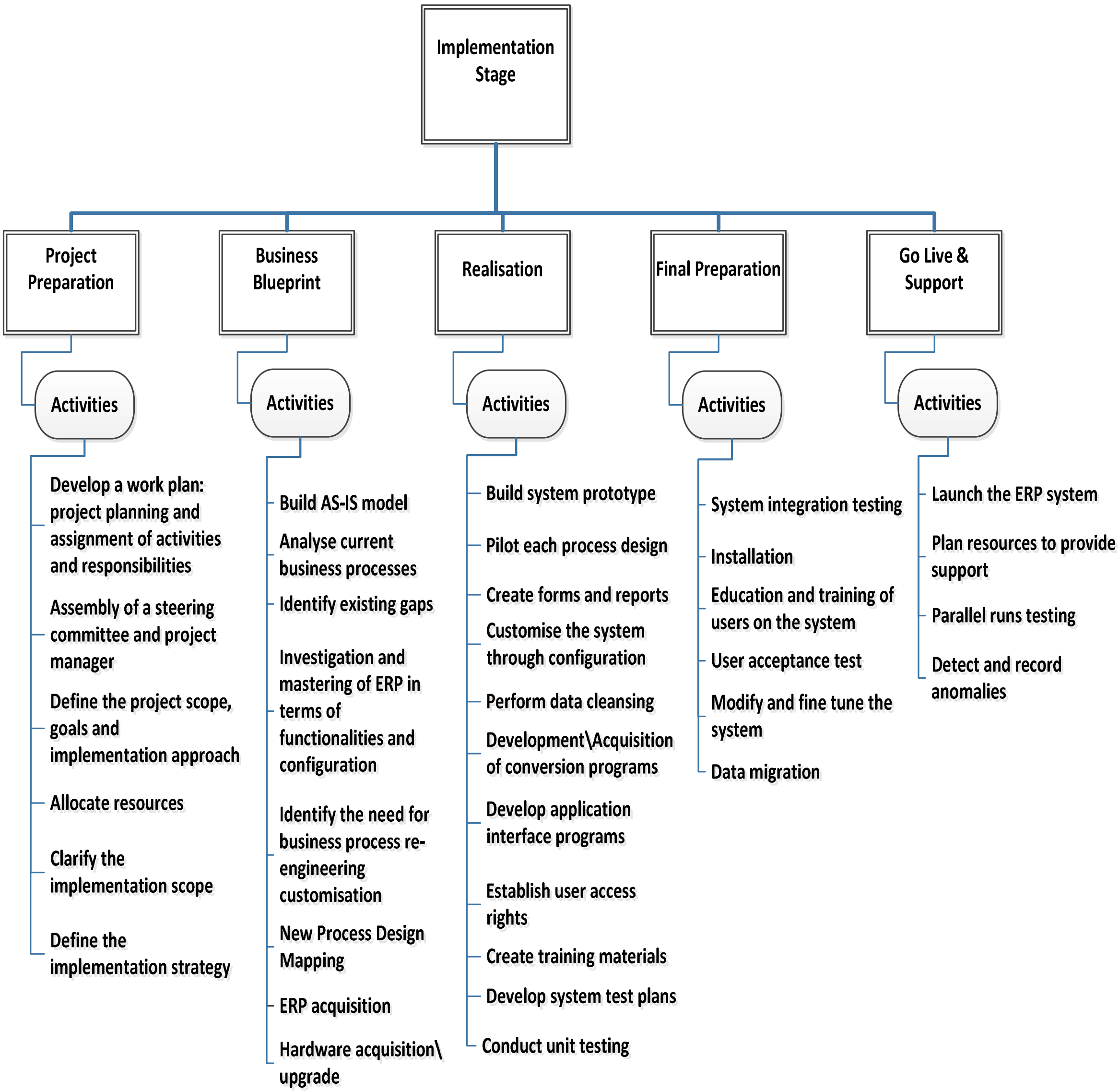



**Figure 2-8:** ERP Implementation Activities and Sub-Activities (Adopted from Iba, 2006)

It is important to note that researchers have described ERP life cycle using different models according to the target application, some with a few general stages (Aloini *et al.,* 2007). The key difference between the life cycles described above is that a Retirement stage is not included in the ERP WLC models of Ross (1999), Somers (2004) and Iba (2006). Additionally, the WLC models of Ross (1999) does not cater for package selection or initiation. And finally, Iba (2006) and Pastor *et al.* (1999) have very similar WLC models, except for the retirement stage which does not exist in Iba's (2006) WLC. Therefore the most comprehensive whole life cycle is that which was defined by Pastor *et al.* (1999).

## 2.4 Understanding Complexity

Throughout history, most projects have contained elements of complexity (PMI, 2014). Complexity is a crucial concern to managers and can undermine operational performance if not managed well, or it could be used as a strategic leverage if managed well (Jacobs, 2013). Solving a problem with software tends to add its own complexity beyond that of the problem itself (Darcy *et al.,* 2005). Radulescu (2006) advises that the attempt to model new domains of human activity has generated very complex software systems. According to Radulescu (2006), business domain complexity has generated complexity within the software product and new technologies have been developed to answer the new business requirements.

ERP systems are complex pieces of software, thereby causing many implementations to be difficult, lengthy and over budget, terminated before completion, and fail to achieve their business objectives even a year after implementation (Somers *et al.,* 2004). Unfortunately, increases in problem complexity may lead to a supralinear increase in software complexity and increases in software complexity may lead to supralinear impacts on managerial outcomes of interest, such as increasing the effort to design, implement and maintain software and reducing its quality (Darcy *et al.,* 2005).

In the study of Shanks *et* al. (2000) where a process model was used to better understand and plan for ERP systems implementation, they report that although some of the ERP problems encountered may be due to poor cost and time estimation, as well as changes in project scope, ERP systems implementation projects are complex and careful planning is critical.

### 2.4.1 Complexity Theory

Mason (2008) and Morrison (2008) explain that complexity theory seeks to understand how order and stability arise from the interactions of many components according to a few simple rules. The rapidly increasing interest and phenomenal development in complexity theory is new and is a relative stranger to the social sciences (Mason, 2008). Complexity theory is a theory of change, evolution, adaptation and development for survival (Mason, 2008; Morrison, 2008). It is associated with organisations, environments, or systems that are complex where very large numbers of constituent elements or agents are connected to and interacting with each other in a variety of ways (Mason, 2008). Mason (2008) and Morrison (2008) discuss emergence and self-organisation as buzz words in complexity theory. Morrison (2008) proceeds to advise that self-organisation is composed of several features; adaptability, open systems, learning, feedback, communication and emergence. The partner of self-organisation is emergence as the former emerges and is internally generated (Morrison, 2008). Karnacias *et al.* (2010) and Mason (2008) imply that given a significant degree of complexity in a particular system, new behaviours and characteristics emerge that are not intrinsic properties of the constituent elements, or able to be predictable from a knowledge of initial conditions, but are manifested by the system as a whole.

### 2.4.2 System of Systems and ERP

Simpson e*t al*. (2009) caution that the increasing rate of systems and system of systems (SoS) design, development, and deployment makes the task of system of systems evaluation, risk and value assessment an increasingly complex task. Simpson *et al*. (2009) define a system as a functional definition (a constraint on variation), or a construction rule definition (a relationship mapped over a set of objects) as advocated by Simpson *et al.* (2008). Therefore, a system of systems is an assemblage of components that may be individually regarded as systems, according to Boardman *et* al. (2006), Simpson *et al.* (2009), and Karcanias *et al.* (2010). By these definitions, an ERP solution is a system of systems and it is complex to implement.

### 2.4.3 Classification of Complexity in Research

In an effort to classify complexity, Jacobs (2013), Radulescu (2006), Simpson *et al*. (2009), Phukan *et al*. (2005), Delugach *et al.* (1997), and Darcy *et al.* (2005) have defined complexity types, factors and dimensions. Although, as Jacobs (2013) and the PMI (2014) emphasise, literature review indicates that complexity is a multidimensional construct which has no standard definition. Karcanias *et al.* (2010) assert that classifying the different aspects of complexity is pertinent. The classification of complexity is illustrated in Figure 2-9.

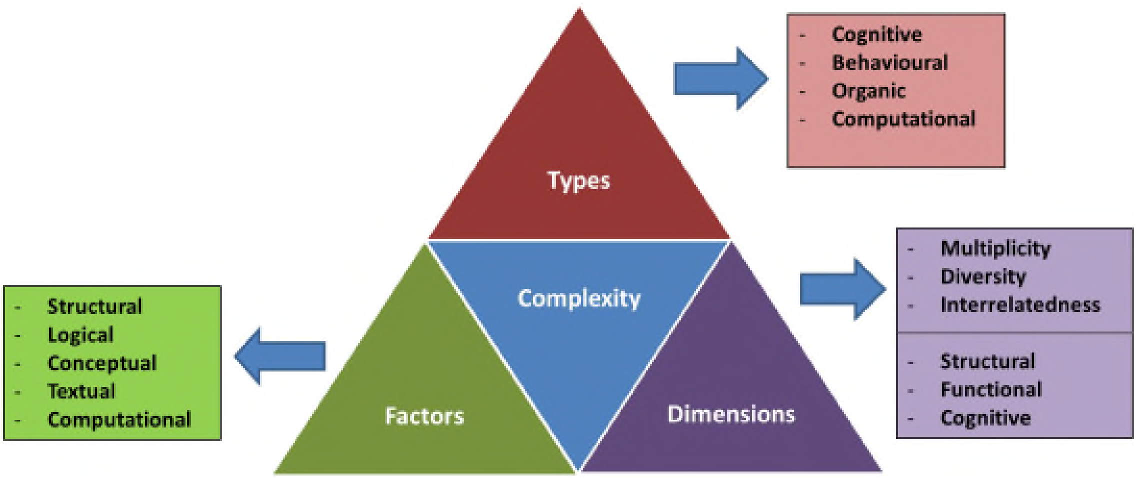



**Figure 2-9:** Classification of Complexity

There is a scale of complexity types which range from cognitive complexity to computational complexity (Simpson *et al.*, 2009). Cognitive and/or perceptual complexity concerns the difficulty experienced by a human to clearly understand the situation (Shao *et al.,* 2003a, b; Simpson *et al.*, 2009). According to Simpson *et al.* (2009), another complexity type is behavioural complexity which is focused on concurrent, reactive and distributed system behaviour. A third type of complexity is organic complexity which is associated with natural organic systems which possess multiple areas of knowledge and information that drive very complex interactions (Simpson *et al.*, 2009). And a fourth complexity type is computational complexity which relates to well-defined problems that efficiently utilise computational hardware, memory and time as advocated by Karnacias *et al.* (2010), Phukan *et al*. (2005), and Simpson *et al.* (2009).

Apart from computational complexity, the other complexity factors contributing to software complexity as defined by Phukan *et al*. (2005) are structural complexity, logical complexity, conceptual complexity and textual complexity. Structural complexity is associated with the topological relationships of a system's components (Darcy *et al.,* 2005; Phukan *et al*., 2005; Radulescu, 2006; Delugach *et al.,* 1997). In terms of logical complexity, it is concerned with the relative difficulty of logical decisions or flows and branches within the system (Phukan *et al*., 2005). The third complexity factor which is conceptual complexity, is related to the physical perception or the relative difficulty of developing a system (Jacobs, 2013; Sessions, 2011; Simpson *et al*., 2009; Phukan *et al*., 2005). As for textual complexity, it applies to the static analysis of program source texts (Phukan *et al*., 2005). Radulescu (2006) defines another complexity dimension as functional complexity which is an inherited complexity from the modelled business domain that cannot be decreased. In relation to functional complexity, although Radulescu (2006) claims that it cannot be measured, the researcher develops a complexity metric for business processes in Chapter 7.

Mason (2008), Morrison (2008) and Jacobs (2013) posit that complexity is a state manifested by the multiplicity, diversity, and functional interrelatedness of elements. As defined by Jacobs (2013), an element is a function or physical component. Furthermore, Jacobs (2013) defines multiplicity as the number of elements including redundant and replicated elements, and diversity as the degree of difference across elements. Interrelatedness is defined as the common or interacting functions inherent in the elements (Karnacias *et al.,* 2010; Project Managament Institute, 2014; Jacobs, 2013; Morrison, 2008). An increase in complexity induces an increase in one or more of the three dimensions (multiplicity, diversity and interrelatedness) characterising the elements (Jacobs, 2013; PMI, 2014).

Another category of complexity is known as application domain complexity, which is defined by Delugach *et al.* (1997) as the complexity in understanding the behaviour of the program reflected by the application domain. Furthermore, Darcy *et al.* (2005) add a complexity facet to the categories, known as algorithmic complexity which consumes machine resources.

It is illustrated in Figure 2-9 that some complexity categories are intertwined. In other words, computational complexity appears in two categories; complexity types and factors. Additionally, cognitive complexity is presented in two categories; complexity types and complexity dimensions. And finally, structural complexity is highlighted in two categories; complexity factors and complexity dimensions. The researcher perceives that algorithmic complexity is similar to computational complexity which is defined by Simpson *et al.* (2009). Also, application domain complexity which is defined by Delugach *et al.* (1997) indicates the same meaning as business domain which falls under functional complexity as defined by Radulescu (2006). Both structural complexity and application domain complexity have the same meaning as conceptual complexity which is defined by Phukan *et al.* (2005). In this literature review, certain complexities have been described in different categories. Therefore, Darcy *et al.* (2005) imply that software complexity cannot be described using a single dimension. The definition of different categories illustrates that a standard definition for complexity has not yet been widely adopted in research nor industry. Therefore, for the purpose of this research, as a considerable number of the various definitions of complexity refers to difficulty, this research defines complexity as the attribute of a system that makes that system difficult to use, understand, manage, implement, and/or has a potential to increase. This definition is adapted from Sessions' (2011) complexity definition.

### 2.4.4 Categorisation of Complexity Causes

The causes of complexity in projects have been grouped into three broad categories by the PMI (2014) as presented in Figure 2-10. The illustration in Figure 2-10 indicates that the three categories of complexity and its associated causes are human behaviour, ambiguity and system behaviour (PMI, 2014).

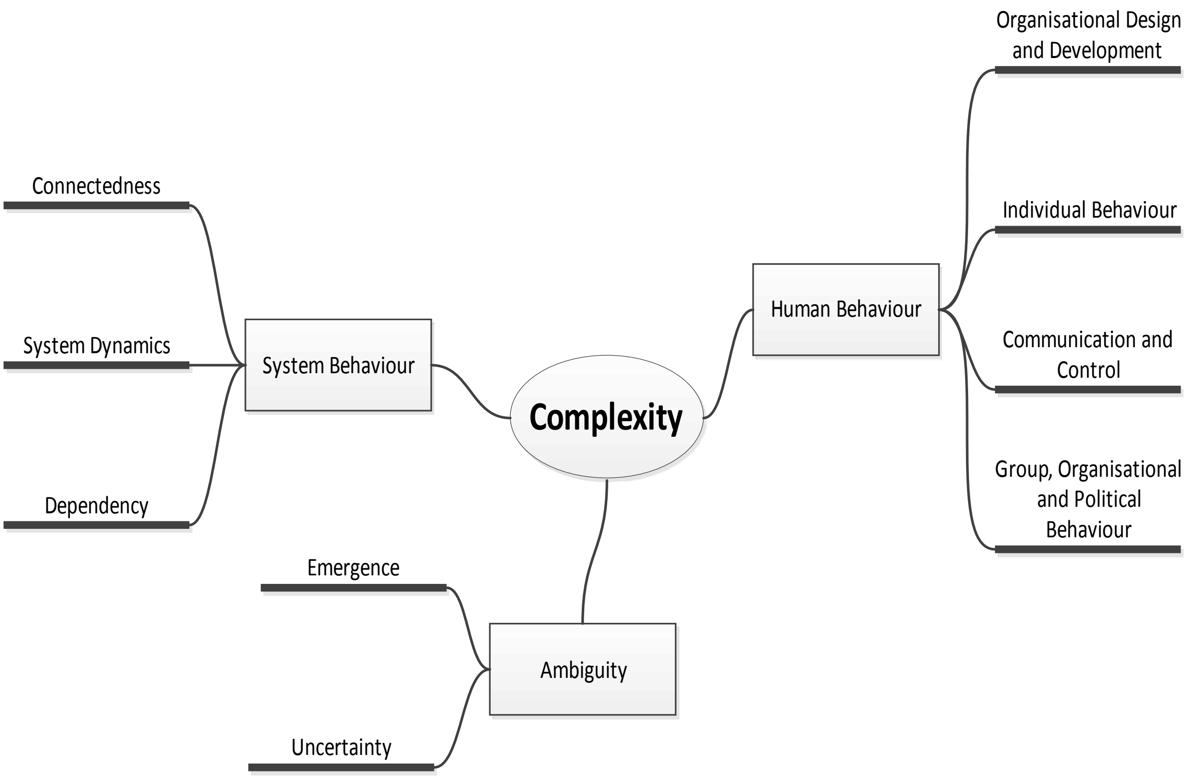



**Figure 2-10:** The Components and Causes of Complexity (Adapted from PMI, 2014)

#### 2.4.4.1 Human Behaviour

According to PMI (2014), human behaviour is the source of complexity that may arise from the interplay of conducts, demeanours and attitudes of people.

These behaviours may be caused by factors such as political influence, and individual experiences and perspectives which may impede the clear identification of goals and objectives. Furthermore, while effective interactions among stakeholders contribute to success, the diversity, influence and number of stakeholders involved in those interactions contribute to the complexity encountered in the program (PMI, 2014).

#### 2.4.4.2 System Behaviour

The PMI (2014) perceive projects and programs as systems of systems. Apparently, in a complex environment, projects and programs are interdependent through connections among their parts or components (PMI, 2014). Therefore, complexity may arise as a consequence of component connections and the existence of disconnects among these components (PMI, 2014). A system is considered to be a collection of different components that together can produce results not obtainable by the components alone (PMI, 2014). PMI (2014) posit that as multiple changes occur in the system and between the system and its environment, adaptive behaviour occurs within the components, which in turn adds to the system's dynamics. The PMI (2014) further classify system behaviour into connectedness, dependency and system dynamics.

#### 2.4.4.3 Ambiguity

Hass (2009) and The PMI (2014) describe ambiguity as a state of being unclear and not knowing what to expect or how to comprehend a situation; this is common in projects with complexity. This cause of complexity is similar to the cognitive complexity dimension defined by Radulescu (2006) and Simpson *et al.* (2009).

There are two ambiguity causes described by PMI (2014) which are emergence and uncertainty. PMI (2014) describe emergence as the unanticipated change, spontaneous or gradual, that occurs within the context of a project, and it may be concealed and later become visible. Emergence is manifested from the dynamic interrelationships among and between components and can appear when a number of processes interact, resulting in new behaviours or new properties (PMI, 2014). Concerning uncertainty as defined by PMI (2014) and Hass (2009), it is the state of being unsure, of not knowing an issue or situation and is described as a lack of awareness and understanding of issues, events, path to follow, or solutions to pursue. It may increase and amplify issues, risks, behaviours, or situations which are internal or external to a project (PMI, 2014).

The definition of complexity in Section 2.4.3 highlights that one of the attributes of complexity is a difficulty in understanding the system. This correlates with one of the characteristics of uncertainty above which stipulates a lack of understanding of issues. The keyword is understanding. A lack of an understanding of system issues will generate a difficulty in understanding, implementing and managing the system which are all attributes of complexity. Furthermore, as uncertainty may increase and amplify issues in the context of an ERP system implementation, this will result in an increase in complexity. This is an indication that uncertainty drives complexity.

### 2.4.5 Complexity Metrics

With the rapid development of large-scaled software, the size of the software system is increasing and the complexity of software grows fast, which makes the quality more and more difficult to control (Yanming *et al.,* 2007; Honglei *et* al., 2009). Shao *et al.* (2003) and Costea (2007) define software quality using the words; completeness, correctness, consistency, maintainability, reliability, interoperability, feasibility and verifiability of the software in both specification and implementation, with no misinterpretation and no ambiguity. Software complexity offers a suitable estimation of the software performance, cost and error factors; it could also create a basis for software system comparison (Rashidi *et al.,* 2010). Malone *et al.* (2013), Honglei *et al.* (2009), Yindun *et al.* (2007), and Nogueira (2012) infer that the cost of software development, testing and maintenance is closely correlated with software complexity. Phukan *et al*. (2005) emphasise that software complexity is the major reason for rapidly increasing software development costs. Therefore complexity drives cost. Consequently, a reduction in software complexity results in a reduction in software costs (Nogueira, 2012; Yindun *et al.,* 2007). Furthermore, as complexity is increased with greater multiplicity of elements (Jacobs, 2013;), an increase in complexity causes an increase in cost. Therefore, it is important that the complexity of any project is measured, in order to obtain a realistic picture of the project cost and the level of risk involved, and to control the software complexity (Yindun *et al.,* 2007; Honglei *et* al., 2009). This further enables the quality of software to be monitored efficiently (Honglei *et al.*, 2009). Honglei *et al.* (2009) define software metrics as a function with input as the software data, and output as a value which could decide on how the given attribute could affect the software. Honglei *et al.* (2009) specify three phases in software measurement as illustrated in Figure 2-11.

According to Honglei *et al.* (2009), software measurement defines, collects and analyses the data of a measurable process, through which it facilitates the understanding, evaluating, controlling and improving of the software product procedure.

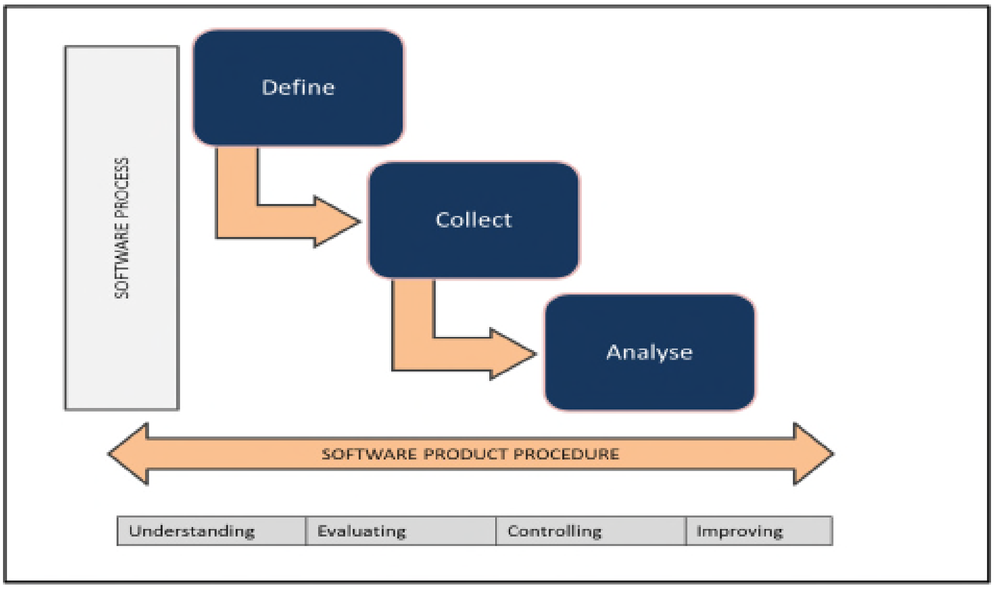



**Figure 2-11:** Software Measurement Cycle

Many software complexity metrics have been proposed in literature (Yanming *et al.,* 2007; Rashidi *et al.,* 2010; Bansal *et* al., 2008; Phukan *et al.,* 2005; Delugach *et al.,* 1997). Software complexity measures serve both as an analyser and a predictor in quantitative software engineering (Shao *et al.,* 2003). Despite the need for complexity measurement, it is argued in literature that no particular metric can measure software complexity in a complete manner (Kevrekidis *et al*., 2009; Yanming *et al.,* 2007; Costea, 2007; Yindun *et al.,* 2007; Rashidi *et al.,* 2010; Du *et al*., 2010; Degulach *et al*., 1997). Therefore, the concept of complexity needs to be expressed as a combination of metrics (Kevrekidis *et al*., 2009; Yanming *et al.,* 2007; Yindun *et al.,* 2007; Rashidi *et al.,* 2010). A comprehensive software metric is yet to be introduced. Hence complexity of software products was, and still is, a widely distributed research topic (Costea, 2007). It is crucial to note that the metrics being referred to by Kevrekidis *et al.* (2009), Yindun *et al.* (2007) and Yanming *et al.* (2007) are applicable to software development, as opposed to ERP implementation. However, some of the metrics can be adapted to ERP projects. Although Stensrud (2001) concludes that specifically, no prediction systems have been devised for ERP projects.

Shao *et al.* (2003a, b) suggests that complexity measures can be classified into two categories; (1) macro complexity measures which are viewed in terms of the resources expended and degree of difficulty in programming, and (2) micro measures which are based on program code and typically depend on program size, program flow graphs or module interfaces. Hamilton *et al.* (2013), Rashidi *et al.* (2010), Honglei *et al.* (2009), Yanming *et al.* (2007), Costea (2007), Yindun *et al.* (2007), Shao *et al.* (2003a, b), and Delugach *et al.* (1997) have mentioned some of the most basic and common software complexity metrics which are LOC (Lines of Code), Halstead complexity measure, IF (Information Flow), and McCabe cyclomatic measure. Other metrics are McCabe's design complexity (Costea, 2007; Rashidi *et al.,* 2010), Control flow complexity (Bansal *et al.,* 2008), and cognitive complexity (Shao *et al.,* 2003a, b).

#### 2.4.5.1 LOC Metrics

The line of code (LOC) metric involves counting the lines of code (excluding comments) in a software program (Phukan *et al.,* 2005; Yanming *et al.,* 2007). Also referred to as physical sizes, the LOC is a well-understood means of measurement and serves the purpose of approximating size and complexity in software systems (Shao *et al.,* 2003b). The physical sizes of software are a reasonably good indicator of the complexity of software, the number of people required for its development, and the expected lifetime of the software (Shao *et al.,* 2003b). Seemingly, an increase in the size of the software creates an increase in defects (Yanming *et al.,* 2007; Yindun *et al.,* 2007). However, the disadvantage of using this metric is the use of software size as the only complexity factor, as a result of a limitation of detailed information available in the early stages of a program (Yanming *et al.,* 2007). Another limitation of this metric according to Phukan *et al.* (2004) is that it is not a suitable indicator at the design phase when the code has not been developed because it is not a good indicator of structural complexity.

#### 2.4.5.2 Halstead Product Metrics

This approach measures software complexity by counting the number of operands and operators (Hamilton *et al.,* 2013; Yanming *et al.,* 2007; Yindun *et al.,* 2007; Phukan *et al.,* 2005; Shao *et al.,* 2003a, b). Halstead used these components to define formula system which is comprised of vocabulary, length, and volume (Yanming *et al.,* 2007). This formula is as follows:

$$\mathbf{Vocabulary}:\ \mathbf{n} = \mathbf{n_1} + \mathbf{n_2} \tag{2-1}$$

$$\mathbf{Length}:\ \mathbf{N} = \mathbf{N_1} + \mathbf{N_2} = \mathbf{n_1} \log_2 \mathbf{n_1} + \mathbf{n_2} \log_2 \mathbf{n_2} \tag{2-2}$$

$$\mathbf{Volume}:\ \mathbf{V} = \mathbf{N} \log_2 \mathbf{n} = \mathbf{N} \log_2 (\mathbf{n_1} + \mathbf{n_2}) \tag{2-3}$$

where: $\mathrm{n_1} = \text{number of distinct operators}$ , $\mathrm{n_2} = \text{number of distinct operands}$ ,

$\mathrm{N_1} = \text{total number of operator occurences}$, $\mathrm{N_2} = \text{total number of operand occurences}$

This method is considered correct as it does not consider the loops and information flow that intensify the complexity (Yanming *et al.,* 2007). For example, two programs with the same lines and same Halstead value will be considered to have the same complexity (Yanming *et al.,* 2007). However, one has straight sequential codes, while the other has very nested loops and tricky information communication (Yanming *et al.,* 2007). Shao *et al.* (2007) argues that the disadvantage of Halstead metrics is that they do not consider the internal structures of software components.

#### 2.4.5.3 Cyclomatic Complexity Metric

Cyclomatic complexity was initially introduced with McCabe complexity metrics (Yanming *et al.,* 2007; Yindun *et al*., 2007). The McCabe cyclomatic complexity metric measures decision points or loops of a program (Hamilton *et al.,* 2013; Yanming *et al.,* 2007; McCabe *et al.,* 1989) and can illustrate the intelligibility, testability and maintainability of the program (Yanming *et al.,* 2007). Cyclomatic complexity utilises a graph which is derived from code (Malone *et al.,* 2013; Yanming *et al.,* 2007; Phukan *et al.,* 2005). McCabe measures software complexity in terms of a dimensionless cyclomatic number (CN) (Malone *et al.,* 2013). CN is defined by Malone *et al.* (2012), Malone *et al.* (2013) and Yanming *et al.* (2007) in Equation 2-4 as follows:

$$\mathbf{CN = e - n + 2p} \qquad \textbf{(2-4)}$$

where n = number of nodes, e = number of edges and

p = number of connected components

Malone *et al.* (2013) provides examples of nodes (*n*) to be organisations or technologies, edges (*e*) to be interfaces or integration, and *p* to be an entity, a group of systems or management groups. Consequently, Malone *et al.* (2013) further define cyclomatic complexity by stating that the cyclomatic complexity of a program, structure or system measures the number of organisations or technologies and interfaces or integrations in a single entity. Malone *et al.* (2012) and Malone *et al.* (2013) state that in a strongly connected software program or SoS, the cyclomatic number is equal to the maximum number of linearly independent interfaces or paths. An increase in system complexity (a higher cyclomatic number) causes an increase in the effort required to develop and maintain the system (Malone *et al.,* 2012; Malone *et al.,* 2013). An illustration of a simple example of cyclomatic elements in a simple SoS is presented in Figure 2-12.

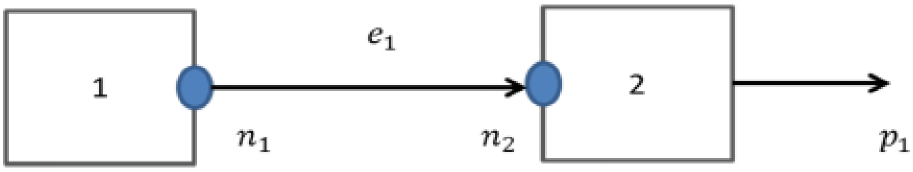



**Figure 2-12:** A Simple Example of the Cyclomatic Elements of Nodes and Edges (Adapted from Malone *et al.,* 2013)

As illustrated by Malone *et al.* (2013) using equation 2-4, based on Figure 2-18, the value CN is calculated as:

$$1 - 2 + 2(1) = 1 \qquad \textbf{(2-5)}$$

Where: n = 2, e = 1 and p = 1.

The disadvantages of McCabe's cyclomatic complexity measure are that it neglects the fact that the sheer length of a program is a factor of complexity (Yanming *et al.,* 2007), it does not consider the inputs and outputs of software systems (Shao *et al.,* 2003a, b), and its graphical method is adequate for small, relatively simple programs and systems (Malone *et al.,* 2013). Malone *et al.* (2013) state that larger, more complex systems require a more structured method for calculating complexity metrics, and one such method is the design structure matrix (DSM).

Malone *et al.* (2013) define the design structure matrix (DSM) as a measurement of complexity which can serve to improve the programmer's understanding of and ability to work with complex systems. One of the factors considered in DSM metrics is the number of interactions to be managed across the elements. This aspect of DSM is applied in this research and is discussed in Chapter 7.

#### 2.4.5.4 Information Flow

Information flow (IF) complexity is a pragmatic basis for measuring large-scale systems, and perhaps the most widely known metric of structural complexity (Yindun *et al.,* 2007). The IF metric measures the system's structure (Yindun *et al.,* 2007) and calculates the information connection between a program's modules (Rashidi *et al.,* 2010; Phukan *et al.,* 2005). The number of local and global flow that emanate and are changed from a module plus the number of data structures that are updated by that module is called a fan-out of the module (Yanming *et al.,* 2007; Bansal *et al*., 2008; Phukan *et al.,* 2005). The information flow from and to a process is quantified in terms of fan-in and fan-out of the process (Bansal *et al*., 2008). Bansal *et al.* (2008), Yanming *et al.* (2007) and Phukan *et al.* (2005) define fan-in as the number of inputs in relation to local direct, indirect and global flows into the process or module. Bansal *et al*. (2008), Yanming *et al.* (2007) and Phukan *et al.* (2005) proceed to define inter-module complexity which is illustrated in Equation 2-6.

$$\text{Inter-module complexity} = \text{Fan-in} + \text{Fan-out} \qquad \textbf{(2-6)}$$

Phukan *et al.* (2005) defines the complexity for each module, as illustrated in Equation 2-7.

$$\mathbf{Complexity} = \mathbf{length}(\mathbf{fan} - \mathbf{in\ x\ fan} - \mathbf{out})^{\mathbf{2}} \qquad \textbf{(2-7)}$$

#### 2.4.5.5 Control Flow Complexity Metric

Bansal *et al*. (2008) state that intra module complexity is measured in terms of control flow complexity of the module. Control flow complexity (CFC) is defined in terms of number of splits and joins (Bansal *et al*., 2008). A decision point splits a path into alternative paths whereas alternative paths get joined into a single path (Bansal *et al*., 2008). Therefore, Process complexity is defined by Bansal *et al*., (2008) in Equation 2-8.

Process Complexity = Inter-module complexity + Intra-module complexity **(2-8)**

Bansal *et al.* (2008) advise that business process configuration (BPC) is complex. Hence intra-module complexity is calculated using a Control Flow Complexity (CFC) factor. As defined by Bansal *et al*. (2008), for a join, CFC count is one; if two paths join at a point, the CFC is 1. At a split, if a process is allowed to follow only one path from n alternatives, CFC is 2n+1 (Bansal *et al*., 2008). If the process is allowed to follow one or more paths from n alternative paths, CFC is n [6] (Bansal *et al*., 2008).

The formulae above are used to calculate process complexity for an ERP implementation.

#### 2.4.5.6 Cognitive Complexity

Shao *et al.* (2003a, b) propose a cognitive complexity metric which is a measure of the cognitive and psychological complexity of software as a human intelligence artefact. Cognitive complexity accounts for both the internal structures of software and the inputs and outputs which it processes (Shao *et al.,* 2003). In order to understand a specified program, the areas of focus are the architecture and the basic control structures (BCSs) of the software (Shao *et al.,* 2003). Shao *et al.* (2003) define BCSs as a set of essential flow control mechanisms that are used for building logical software architectures. The cognitive weight of each BCS determines a component's functionality and complexity (Shao *et al.,* 2003a, b). The cognitive weight of software is the degree of difficulty or relative time and effort required for understanding a specified piece of software modelled by a number of BCSs (Shao *et al.,* 2003a, b). The cognitive functional size (CFS) of a basic software component which only consists of one method is defined as a product of the sum of inputs and outputs and the total cognitive weights (Shao *et al.,* 2003a, b).

#### 2.4.5.7 McCabe's Design Complexity Metric

Rashidi *et al.* (2010) state that the MCCabe design complexity metric reflects the complexity of module structures and module call pattern to subjects.

Therefore, it provides a suitable basis for calculating the degree of design and integration complexity (Rashidi *et al.,* 2010).

#### 2.4.5.8 Variety, Variability and Integration Complexity Metrics

Ribbers *et al.* (2002) defines three dimensions of measure for package implementation complexity: (1) variety which reflects the number of elements and their interrelations in a given situation or system, and it increases with, for example, the number of sites affected or the functions of a package implemented; (2) variability which relates to the dynamics over time of its elements and the interrelations between them, for example, scope changes, lack of resources or dependencies on other programs that are competing for resources; and (3) integration which characterizes the planned changes to be realized through the implementation program in terms of integration of IT systems and across business processes. In order to determine the overall complexity of an implementation program and its complexity level as it relates to each dimension of measure, Ribbers *et al.* (2002) identified complexity indicators which are specified in Table 2-2, and relative weights of each indicator. Relative weights are applied because the relative importance of all the indicators is not the same (Ribbers *et al.,* 2002). The proposed weights are on a scale of 1 to 5 and represent the relative impacts of complexity variables, as perceived by program managers (Ribbers *et al.,* 2002).

The integration measure in Table 2-2 is categorised into technical integration,social integration, structural integration, and process integration. These categories are depicted in Figure 2-13.

Based on the definition of integration complexity above, Ribbers *et al.* (2002) provide a differentiation of reach and range for IT platforms, which provides an adequate framework for description.

**Table 2-2**: Ribbers *et al.* (2002) Complexity Measures

| **Complexity Measure** | **Complexity Indicators** |
|---|---|
| Variety | • Number of affected locations<br>• Readiness in terms of organisational differences, and level of negative predisposition from experiences in earlier, similar programs.<br>• Conversion effort in terms of level of data misfit and number of systems to be replaced |
| Variability | • Level of availability of resources in terms of availability of adequately trained and experienced project staff<br>• Level of concurrent similarly complex programs<br>• Extent of system redesign after pilot<br>• Extent of goal and scope changes |
| Integration | • Technical integration<br>• Social integration<br>• Structural integration<br>• Process integration |

Ribbers *et al.* (2002) convey that IT integration primarily concerns IT infrastructure. In relation to organisational integration, the dimensions of reach and range discover their counterparts in the organisational boundaries and processes in the organisation (Ribbers *et al.,* 2002). An increased reach and range goes together with crossing of organisational boundaries as business processes span more organisational functions (Ribbers *et al.,* 2002). Therefore, Ribbers *et al.* (2002) specify process and technical integration on four axes; (1) reach, ranging from ‘within location’ to ‘all over the world, (2) range, ranging from ‘single, local support’ to ‘cooperative transactions’, (3) process, ranging from ‘internal process’ to ‘external process’, and (4) organisational boundary, from ‘team internal’ to ‘external partners’. The axes further characterise different levels of process flow capabilities within or between organisations as intra-team, inter-team, intra-organisational, and inter-organisational (Ribbers *et al.,* 2002). Ribbers *et al.* (2002) asserts that integration complexity is calculated as the average deltas between the levels of integration on these axes before and after an implementation program. Similar to the other two complexity variables, integration complexity is transposed onto a scale of 1 to 5 (Ribbers *et al.,* 2002).

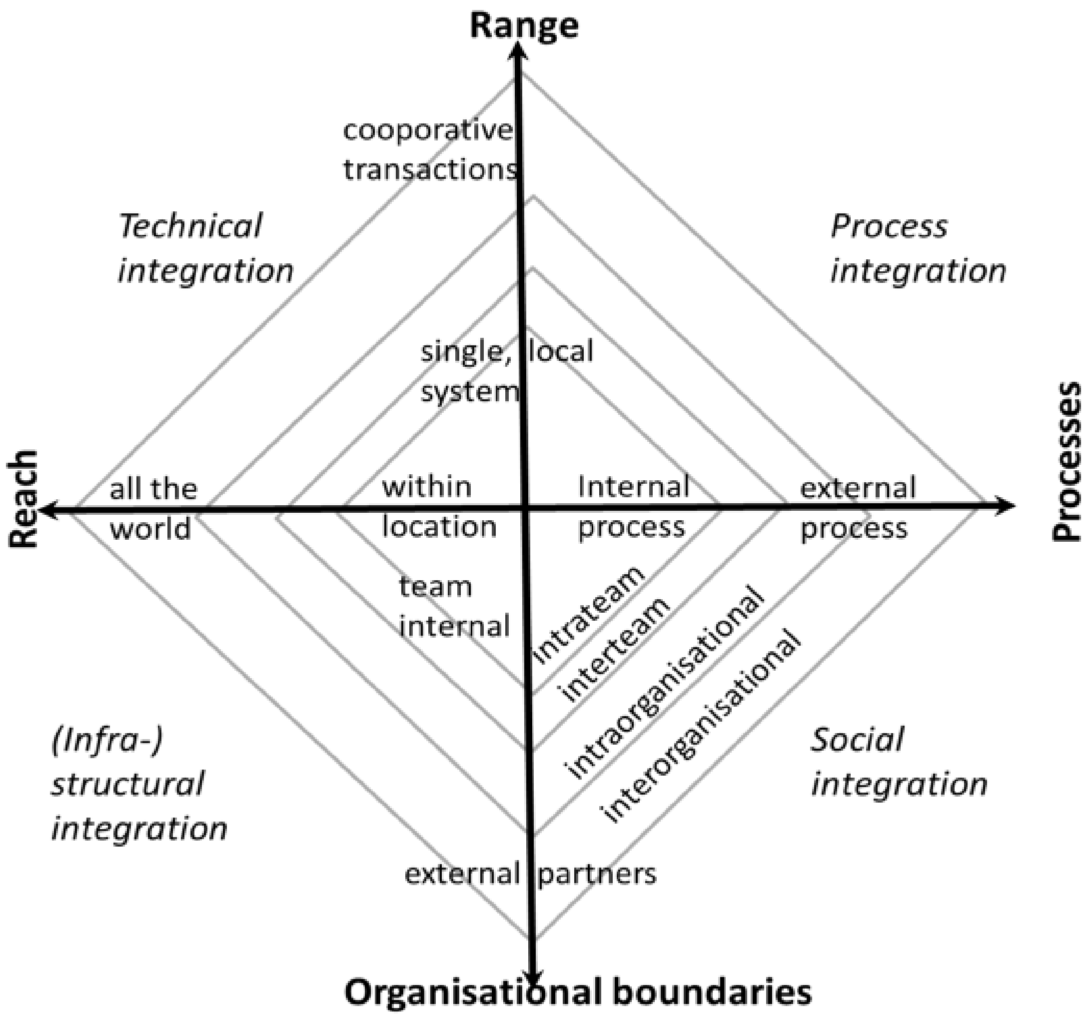



**Figure 2-13:** Levels of Integration (Adapted from Ribbers *et al.,* 2002)

From the researcher's perspective, the measures variety, variability and integration can be applied to ERP implementations, as they are designed for package implementations. The indicators may be used in ERP implementations, and could even be extended. However, it is not clear as to the method which is applied in deriving the complexity level. Therefore, it may not be thorough enough to capture complexity levels for ERP implementation indicators. Secondly, determining the proposed weights seem subjective as it does not entail a stringent structure thereby exposing the weights to bias.

There is very little literature on ERP complexity. Most of the papers available focus on software complexity, which addresses coding. Bansal et al. (2008) emphasise that it is hard to comprehend the complexity of an ERP implementation project, especially when ERP software is a semi-finished product that requires only configuration and no programming. Ribbers (2002) defines complexity from a program management of ERP implementation perspective, and attempts to explore how the design of program management can contribute to the success of complex software implementations. Therefore, whilst Ribbers' (2002) studies complexity from an ERP program-wide perspective, Bansal et al. (2008) and Brown *et al*. (2004) discern it from an ERP system configuration angle, and McCabe *et al*. (1994) focus on software complexity in general. Radulescu (2006) discusses complexity from a software quality and software maintenance angle. Irrespective of the perspective from which ERP complexity is viewed, it is essential that managers focus on reducing or managing complexity in order to deliver these projects successfully.

## 2.5 Linking Critical Failure Factors, Challenges and Complexity in ERP

The literature review on ERP critical failure factors indicates that the terminologies complexity, failure and challenge are closely interrelated. Figure 2-14 illustrates the three concepts which affect ERP systems implementations.


**Figure 2-14:** The Link between ERP Complexity, Failure and Challenge

From the researcher's experience, a challenge is a problem encountered which could be caused by a complexity that could potentially lead to failure. As stated by Bansal *et al.* (2008), a reason for software failure is its complexity. Assigning critical failure factors to complexity categories is illustrated in Table 2-3. This establishes a critical failure factor as a complexity. The categories are structural, functional, cognitive and computational. The '√' in Table 2-3 is used to indicate a relationship between the CFF and complexity dimension, while 'x' is an indication that there is no relationship between these variables.

**Table 2-3:** Mapping Critical Failure Factors to Complexity Dimensions

| | Complexity Category | | | |
|---|---|---|---|---|
| **Critical Failure Factor** | **Structural** | **Functional** | **Cognitive** | **Computational** |
| Excessive Customisation | √ | x | x | √ |
| Dilemma of Internal Integration | √ | √ | x | x |
| Misalignment of IT with Business | x | √ | x | x |
| Poor Data Quality | √ | x | x | x |
| Poor Understanding of ERP Business Requirements | x | √ | √ | x |
| Organisational, Management and Technical Challenges | √ | √ | x | √ |
| Lack of Change Management | x | √ | x | x |
| Hidden Costs in ERP Implementation | √ | x | x | x |

The complexity categories have already been described in Section 2.4.3. According to the definitions of these categories, the researcher has mapped the ERP CFFs to the four dimensions in Table 2-3.

## 2.6 Classification of ERP Complexities

In this literature review, dimensions, types and factors have been used to categorise complexity. As some categories appear in other categories, the researcher will use the terminology category in this research to classify ERP complexities at the highest level. The terminology dimension will be used in Chapter 5 to further classify the complexity categories. The types of complexity will be referred to as complexity types in this research. Therefore, an example of a complexity type is functions (or components), which falls under the structural complexity category. The researcher has selected six complexity categories from the findings in this literature review. These complexity categories are functional, structural, cognitive, variety, variability and integration. These six complexity categories are a combination of Ribbers' (2002) dimensions of complexity measure, and Radulescu's (2006) complexity dimensions. These categories were defined in order to classify the characteristics of complexity to reflect multiplicity, diversity, interrelatedness, emergence of elements, and difficulty in understanding project situations. The definitions of the complexity categories functional, structural and cognitive in Section 2.4.3 and variety, variability and integration in Section 2.4.5.8 apply to the complexities developed in this research. The complexity factors which have been studied in this literature review are linked to the six complexity categories. An illustration of linking each complexity factor with a complexity category is provided in Table 2-4. These complexity factors are used as the basis for defining the content of the semi-structured questionnaire which is used to facilitate the case study interviews presented in Chapter 4. The findings from the case study and the complexity factors in Table 2-4 are applied in the development of the complexity taxonomy implemented in the framework of this research.

The categories which have not been selected are not applicable to this research, as they are related to the computation and behaviour of hardware. The focus of this thesis is on the business application, enterprise resource planning which is a software package.

**Table 2-4:** Linking Complexity Types to Complexity Dimensions

| | | **Complexity Category** | | | | | |
|---|---|---|---|---|---|---|---|
| **Complexity Factors** | **Author** | **Variety** | **Variability** | **Integration** | **Functional** | **Structural** | **Cognitive** |
| Database Configuration | Bansal et al. (2008) | | | | | | |
| Network System Configuration | Bansal et al. (2008) | | | | | | |
| Operating System Configuration | Bansal et al. (2008) | | | | | | |
| Computer Configuration | Bansal et al. (2008) | | | | | | |
| Number of Concurrent Users | Bansal et al. (2008), Borisowich (2009) | | | | | | |
| Business Process Configuration | Bansal et al. (2008), Radulescu (2006) | | | | | | |
| Departments | Bansal et al. (2008) | | | | | | |
| Activities | Bansal et al. (2008) | | | | | | |
| Business Process Relationships | Bansal et al. (2008) | | | | | | |
| Data Definition and Configuration | Bansal et al. (2008) | | | | | | |
| Functions | Bansal et al. (2008), Radulescu (2006) | | | | | | |
| Modules | Bansal et al. (2008) | | | | | | |
| Number of Technologies | Borisowich (2009) | | | | | | |
| Experience with Technologies | Borisowich (2009) | | | | | | |

| Complexity Factors | Author | Variety | Variability | Integration | Functional | Structural | Cognitive |
|---|---|---|---|---|---|---|---|
| Application Size | Borisowich (2009) | | | | | | |
| Schedule | Borisowich (2009) | | | | | | |
| Team Members Average Yrs of Experience | Borisowich (2009) | | | | | | |
| Reliance on Third Party Labour | Borisowich (2009) | | | | | | |
| Nature of Contract | Borisowich (2009) | | | | | | |
| Operational Performance Requirements | Borisowich (2009) | | | | | | |
| Number of Affected Locations | Borisowich (2009); Ribbers (2002) | | | | | | |
| Countries and Languages | Borisowich (2009) | | | | | | |
| Readiness (Organisational Differences between Locations) | Ribbers (2002) | | | | | | |
| Effort Required to Understand Software Product | Simpson *et al.* (2009), Radulescu (2006), Shao *et al.* (2003a, b), Delugach *et al.* (1997) | | | | | | |
| Level of Negative Predisposition from experience in similar/earlier programs | Ribbers (2002) | | | | | | |
| Conversion Effort in terms of Level of Data Misfit | Ribbers (2002) | | | | | | |
| Number of Systems to be Replaced | Ribbers (2002) | | | | | | |
| Level of Availability of experienced/trained Resources | Ribbers (2002) | | | | | | |
| Level of Concurrent Similarly Complex | Ribbers (2002) | | | | | | |

| **Complexity Factors** | **Author** | **Variety** | **Variability** | **Integration** | **Functional** | **Structural** | **Cognitive** |
|---|---|---|---|---|---|---|---|
| Programs | | | | | | | |
| Extent of System Redesign after Pilot | Ribbers (2002) | | | | | | |
| Extent of Goal and Scope Change | Ribbers (2002)<br>Ribbers (2002) | | | | | | |
| Technical Integration | Ribbers (2002), | | | | | | |
| Social Integration | Ribbers (2002) | | | | | | |
| Structural Integration | Ribbers (2002) | | | | | | |
| Excessive Customisation | Janols *et al. (*2013), Faasen *et al. (*2013), Khanna *et al. (*2012), Huang *et al, (*2012), Jharkharia (2011), Snider *et al. (*2009), Thermistocleous (2001), Shehab *et al*. (2004), McAdam *et al*. (2005), Chung *et al*. (2000), Aloini *et al*. (2007), Verma (2007), Vogt (2002), Davenport (1998), Sumner (1999), Kogetsidis *et al.* (2008) | | | | | | |
| Dilemma of Internal Integration | Tarn *et al.* (2002), Soh *et al.* (2000), Themistocleus *et al.* (2001), Davenport, (1998), Aloini *et al*. (2007), Youngberg *et al.* (2009) | | | | | | |
| Misalignment of IT with Business | Ho et *al*. (2004),<br>Momoh *et al.* (2010) | | | | | | |
| Poor Data Quality | Momoh *et al.* (2010), Youngberg et *al*. (2009), Glowalla *et al.* (2014), Gullkvist (2013), Vosburg *et al.* (2001), | | | | | | |

| Complexity Factors | Author | Variety | Variability | Integration | Functional | Structural | Cognitive |
|---|---|---|---|---|---|---|---|
| | Strong et *al*. (1997), Hongjiang et *al*. (2002), Soh et *al*. (2000), Alshawi et *al*. (2004), Park *et al.* (2005) | | | | | | |
| Poor Understanding of ERP Business Requirements | Yusuf *et al*. (2004), Ehie *et al.* (2005) Langenwalter (2000); Soh et *al*. (2000); Davenport (1998); Kogetsidis et *al*. (2008) | | | | | | |
| Organisational, Management and Technical Challenges | McAdam *et al.* (2005), Huang *et al.* (2003), Momoh *et al.* (2010), Huang et *al*. (2004) | | | | | | |
| Lack of Change Management with Training Challenges | Almajed *et al.* (2013), McAdam *et al.* (2005), Hong *et al.* (2002), Aloini *et al*. (2007), Kamhawi (2008), | | | | | | |
| Hidden Costs in ERP Implementation | Yusuf et *al*. (2004), Wheatley (2000), Momoh *et al.* (2010), Glowalla *et al.* (2014), Tarn *et al.* (2002), Slater (1998), Soh *et al.* (2000) | | | | | | |

The complexity factors in Table 2-4 will be analysed in Chapter 5, and a reduced version will be adopted in this research. A further set of complexity dimensions specified by Kumar (2011) were identified by the researcher. These dimensions are presented in Figure 2-15. Each dimension is further classified into a set of complexities.

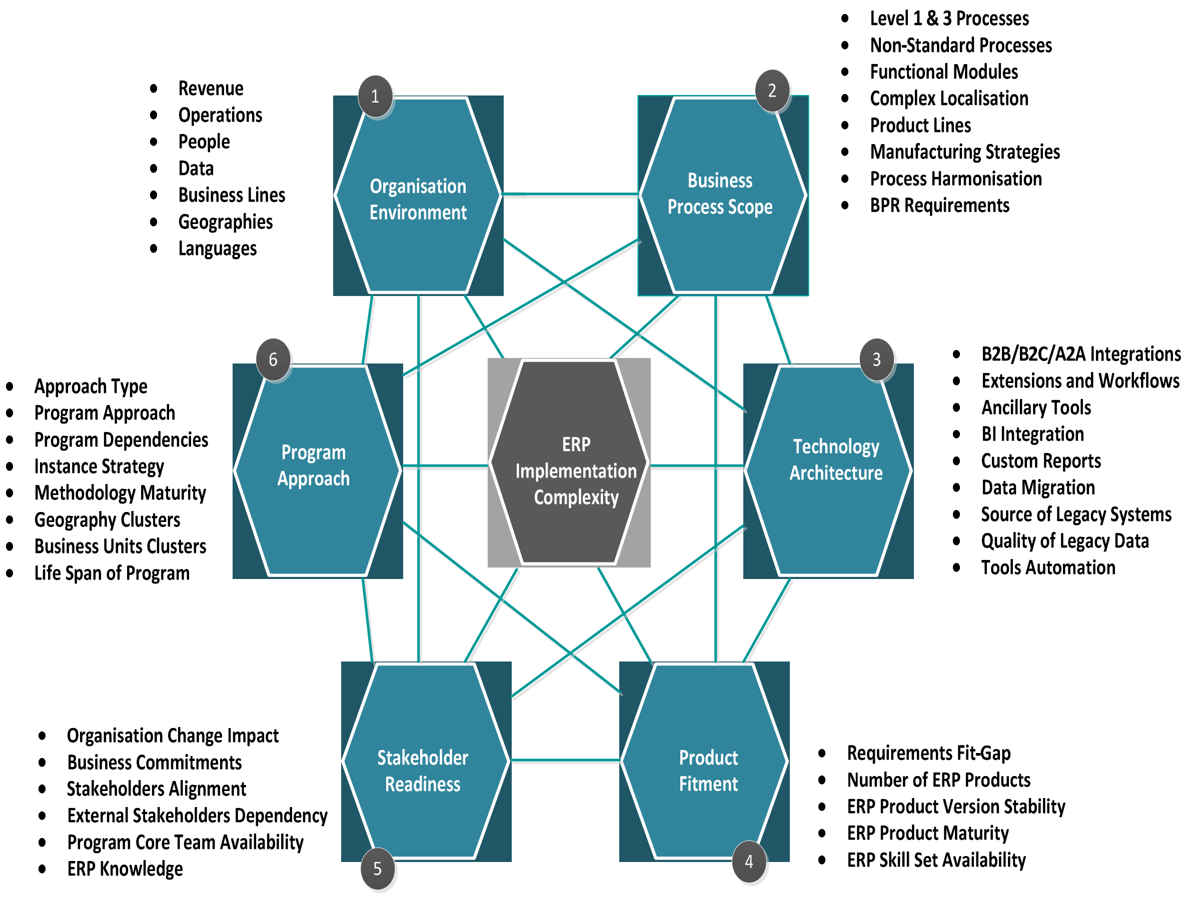



**Figure 2-15:** Kumar's Complexity Dimensions (Adapted from Kumar, 2011)

## 2.7 ERP Life Cycle Costing

This section reviews various ERP costing techniques in order to enable the researcher to select the most appropriate one to apply in the costing of the project implementation activities and resources to which the identified complexities are attached. Leung *et al*. (2002) define software cost estimation as the process of predicting the effort required to develop a software system. Leung *et al*. (2002) stipulate that the bulk of the cost of software development is due to the human effort, and most cost estimation methods focus on this aspect and give estimates in terms of person-months. Underestimating the costs may result in management approving proposed systems that exceed their budgets, with underdeveloped functions and poor quality, and failure to complete on time (Leung *et al*., 2002).

Estimation of effort and duration of ERP implementation and software development activities has become a topic of growing importance, as there is not yet a widely accepted technique. In Stensrud's (2001) research, he wondered if the existing body of knowledge developed for software cost estimation was applicable to estimation of ERP implementation effort. This concern is indicative of the notion that there is minimal research on ERP cost estimation in comparison to software development costing.

Boehm *et al*. (2000) describes software engineering cost (and schedule) models and estimation techniques as being used for; (i) budgeting, (ii) tradeoff and risk analysis, (iii) project planning and control, and (iv) software improvement investment analysis.

Heemstra (1992) cautions that there are many reasons why cost estimation is so difficult, one of which is that clear, complete and reliable specifications are difficult to formulate, especially at the start of a project.

Equey *et al*. (2009) report that several cost estimation approaches exist, such as the *constructive cost model* (COCOMO). The approach states that under normal circumstances, development costs are a function of project size (Equey *et al,*.2008). However, Stensrud (2001) infers that ERP projects are estimated by using a multi-dimensional project size measure, even though there is no internationally agreed upon "project size" standard for these projects.

### 2.7.1 Cost Estimation Techniques

This section discusses the cost estimation techniques that are used for estimating a software project. Some of these techniques also apply to ERP project costing. Figure 2-16 depicts the costing techniques. Cost models which are widely employed are of two categories; algorithmic models, and non-algorithmic models (Roy and Rush, 2001).

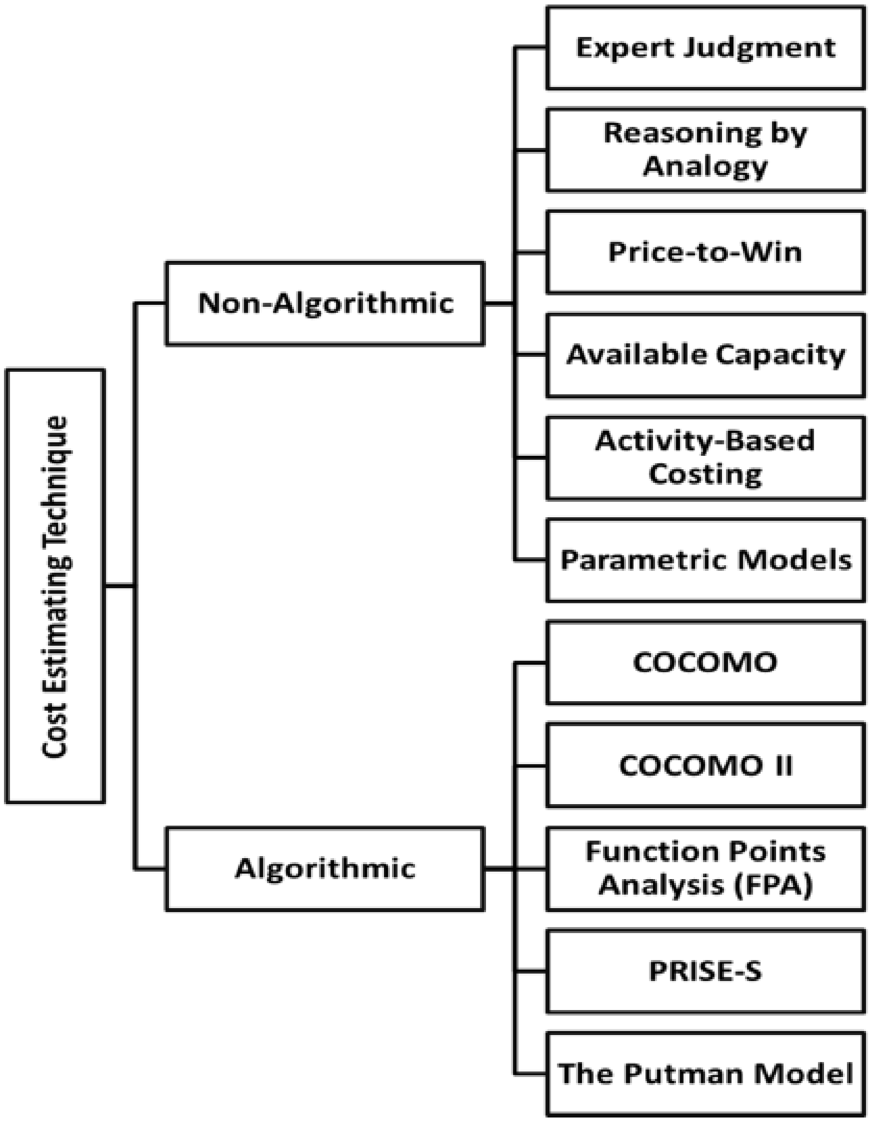



**Figure 2-16:** Cost Estimation Techniques

#### 2.7.1.1 Non-Algorithmic Cost Estimation Techniques

Heemstra (1992) deduces that most cost estimation techniques are a combination of the following primary techniques:

- Estimates made by an expert

- Estimates based on reasoning by analogy
- Estimates based on Price-to-Win
- Estimates based on available capacity
- Estimates based on the use of parametric models

Leung *et al.* (2002) and Attarzadeh *et* al. (2010) define these techniques as non-algorithmic. Ahmed *et* al. (2009), Roy and Rush (2001) and Leung *et al*. (2002) also support Heemstra's (1992) techniques by further advising that the widely practiced cost estimation method is expert judgment. However, it is argued that there is a problem in applying expert judgement because experts provide information in a qualitative and imprecise form (Ahmed *et* al., 2009, Musilek *et al*., 2002). Hence, the need for models that are able to handle both quantitative and qualitative information simultaneously (Ahmed *et al*., 2000).

**Expert judgment** is a method which involves one or more experts, whom provide estimates using their own methods and experience (Leung *et al*., 2002). Roy and Rush (2001) advise that although it is widely used for generating estimates, it is prone to bias. Subjectivity is an issue that surrounds the compilation of all cost estimates and the use of expert judgment is unavoidable (Roy and Rush, 2001). Expert judgment also has its limitations, some of which are outlined by Roy and Rush (2001) as:

- Subjective
- Risky and prone to error
- Three experts with the same starting information will produce different cost estimates
- Prone to bias; personal experience, political aims, resources, and time pressure.
- Estimate reuse and modification is different

**Reasoning by Analogy** costing is a method that requires one or more completed projects that are similar to the new project and derives the estimation through reasoning by analogy using the actual costs of previous projects (Leung *et al*., 2002, Erkoyuncu *et al*., 2009). Roy and Rush (2001) posit that using analogies for the basis of estimating is not new. It is widely accepted that the most common way in which experts produce cost estimates and make judgments is by analogy (Roy and Rush*,* 2001). Additionally, price-to-win is a method whereby the software cost is estimated to be the best price to win the project (Leung *et al*., 2002).

Heemstra (1992) distinguishes two main cost estimating approaches; top-down and bottom-up. In the top-down approach, the estimation of the overall project is derived from the global characteristics of the product (Heemstra, 1992; Hass, 2009). The total estimated cost is then split up among the various components (Heemstra, 1992, Leung *et al.,* 2002). Leung *et al*. (2002) advises that this approach is suitable for cost estimation at the early stage. This cost estimating technique is also referred to as activity-based costing, which is adopted in this research. Heemstra (1992) defines the bottom-up approach to be one where the cost of each individual component is estimated by the person who will be responsible for developing the component. Bottom-up estimates are also referred to as task-oriented estimates and are calculated using a detailed work breakdown structure (Hass, 2009). The individual estimated costs are summed to get the overall cost estimate of the project (Heemstra, 1992, Leung *et al.,* 2002).

Activity-based costing (ABC) was initially geared towards manufacturing (Raj and Elnathan, 1999). Therefore, there is very little literature on ABC for IT and ERP projects. Activity-based costing is a methodology that reveals the cost structure of products and the activities required to manufacture the products (Kim, 2009). The products in the context of this research are ERP systems. ABC has enabled many organisations to improve their competitiveness by allowing them to make better decisions based on a better understanding of their cost structure (Raz and Elnathan, 1999). Activity-based costing allows the linking of activities, cost drivers and costs which enable managers to analyse potential cost changes due to changes in activities (Raj and Elnathan, 1999). Neumann *et al.* (2004) posit that cost drivers are the first link in the ABC model, placed between the resource and the activity. The ability to measure all activities associated with software production has led to the concept of activity-based studies of software costs (Jones, 1996). The application of ABC involves the association of an average number of work hours with each activity or task (Jones, 1996). This enables the assembly of effort and cost estimates by selecting the activities which will be performed for a given project, aggregating the effort and applying the standard cost (Jones, 1996). Neumann *et al.* (2004) and Kim (2009) stipulate that activity systems consist of three elements: resource, activity and cost objects, where cost objects consume activities, activities consume resources, and resources consume costs. Each type of activity is then accounted for individually based on the total cost of resources consumed divided by the volume of activity performed (Raz and Elnathan, 1999).

An ABC approach has a two-stage process where the first stage transfers costs associated with resource consumption to activities, and the second stage allocates activity costs to products (Kim, 2009; Raz and Elnathan, 1999). Therefore, Kim (2009) proceeds to define the ABC analysis of an ERP system as follows:

1. Estimate overall cost of implementing an ERP system and define possible resources based on cost elements of an ERP system
2. Construct resource cost pools and develop resource cost drivers
3. Define main activities which consume ERP resources and calculate a total cost of each activity
4. Identify the second stage cost drivers and allocate activity costs to products using the cost driver

Hass (2009) advise that expert judgment is the basis for the top-down and bottom-up cost estimating techniques.

### 2.7.1.2 Algorithmic Cost Estimation Techniques

Algorithmic methods are based on mathematical models that produce cost estimate as a function of a number of variables, which are considered to be major cost factors (Leung *et al.*, 2002, Attarzadeh *et al*., 2010).

The costing techniques which are categorized as algorithmic by Leung *et al.* (2002) and Heemstra (1992) are:

- COCOMO
- FPA (Function Point Analysis)
- Linear models
- Multiplicative models
- Power function models
- Putman's model and SLIM
- Discrete models
- BYL (Before You Leap)
- Estimacs
- SPQR-20
- BIS-Estimator
- Price-S
- SoftCost

#### 2.7.1.2.1 Function Point Analysis

The function point analysis (FPA) enables calculations of productivity, functionality, effort, or cost by measuring software size (Phukan *et al.,* 2005; Shao *et al.,* 2003b; Low *et al.,* 1990; Barnes *et al.,* 1993). Symons (1988) stipulates that FPA is based on two factors; (1) information processing size which is a measure of the information processed and provided by the system, and (2) a technical complexity factor, which is a factor that accounts for the size of the various technical and other factors involved in developing and implementing the information processing requirements. Phukan *et al.* (2005), Shao *et al.* (2003b), Abran (1996) and Symons (1988) specify that the FP metric uses functional and logical entities such as external inputs, external outputs, internal logical data file, external logical data file and inquiries to measure the functions performed by a given software system. This metric was introduced by Allan J. Albrecht, and since its advent, its definitions and measurements have evolved phenomenally (Shao *et al.,* 2003b).

Shao *et al.* (2003b) define FPs as a weighted measure of software functionality which is determined by a function of the number of inputs, outputs, data objects, and internal processes as indicated in Equation 2-9.

FP = f(#inputs, #outputs, #data_objects, #processes) **(2-9)**

Phukan *et al.* (2005), Shao *et al.* (2003b) and Symons (1988) specify the value of function points as the product of the Unadjusted FPs (UFP) and the Technical Correction Factors (TCFs) as indicated in Equation 2-10. Although Phukan *et al.* (2005) refers to TCF as a value adjustment factor (VAF).

FP = UFP x TCF **(2-10)**

Shao *et al.* (2003b) define UFP as a weighted sum of numbers of function items as illustrated in Table 2-5:

$$\mathbf{UFP = 4N_1 + 5N_2 + 10N_3 + 7N_4 + 4N_5} \quad \textbf{(2-11)}$$

Phukan *et al.* (2005) and Shao *et al.* (2003b) define TCF as a weighted sum of 14 affective degrees of the general system characteristics (GSKs). The 14 degrees of GSKs (GSK *j*) are presented in Table 2-6. TCF is illustrated in Equation 2-12.

$$\mathbf{TCF = 0.65 + 0.01 \sum_{j=1}^{14} d_j} \quad \textbf{(2-12)}$$

**Table 2-5:** Definition of the Functional Factors (Adapted from Shao *et al.,* 2003b)

| **Factor** | **Symbol** | **Description** |
|---|---|---|
| $N_1$ | $N_i$ | # of external inputs |
| $N_2$ | $N_o$ | # of external outputs |
| $N_3$ | $N_{If}$ | # of internal logic files |
| $N_4$ | $N_{if}$ | # of internal files |
| $N_5$ | $N_q$ | # of external inquiries |

Phukan *et al.* (2005) and Shao *et al.* (2003b) specify that each GSK is assessed on a scale of 0 (none) to 5 (essential), and Shao *et al.* (2003b) specify $d_j$ as an effective degree to system development of each GSK. Based on Equation 2-12, the range of TCF can be determined within 0.65 to 1.35 (Shao *et al.,* 2003b).

**Table 2-6:** Definition of the General System Characteristics (Adapted from Shao *et al.,* 2003b)

| $\boldsymbol{GSK_j}$ | **Description** | $\boldsymbol{GSK_j}$ | **Description** |
|---|---|---|---|
| 1 | Data recovery and back-up | 8 | Online update of master files |
| 2 | Data communication | 9 | Complex functionality |
| 3 | Distributed processing | 10 | Internal processing complexity |
| 4 | Performance issues | 11 | Reusability |
| 5 | Heavily used configuration | 12 | Installation ease |
| 6 | Advanced data entry and lookup | 13 | Multiple sites |
| 7 | Online data entry | 14 | Modifiability |

Function points are a derived measure for the attributes of functionality provided by a software system, and is widely used and accepted in the software industry (Shao *et al.,* 2003b). However, as Shao *et al.* (2003) emphasised, the FP metric is also a subjective measure affected by the selection of a large set of weights, with wide ranges of variation, and the physical meaning of the basic unit of a function point is still ambiguous.

Although Boehm *et al*. (2000) and Stensrud (2001) have also defined some of the above mentioned techniques, Boehm *et al*. (2000) split software estimation techniques into six groups:

- Model-Based; SLIM, COCOMO, Checkpoint, and SEER.
- Expertise-Based; Delphi and Rule-Based.
- Learning-Oriented; Neural and Case-Based.
- Dynamics-Based; Abdel-Hamid-Madnick
- Regression-Based; OLS (Ordinary Least, and Robust.
- Composite; Bayesian-COCOMO II

Daneva (2008) stresses that COCOMO II is one of the best-known algorithmic models for setting budgets and schedules as a basis for planning and control. It comprises (i) five scale factors, which reflect economies and diseconomies of scale observable in projects of various sizes, and (ii) 17 cost drivers, which serve to adjust initial effort estimations (Daneva, 2008). Daneva (2008) advises that COCOMO II allows ERP teams to include in their estimates; (i) the maturity level of the ERP adopting organization, (ii) the extent to which requirements' and system architecture's volatility is reduced before ERP configuration, and (iii) the level of team cohesion and stakeholders' participation.

Different metrics consider different factors due to the inability of any single metric designer to comprehensively consider all factors that would indeed contribute to the definition of the characteristic (Ahmed *et al*, 2009). Therefore, it is practical to employ different suitable metrics in cost estimation, depending on the situation. Genuchten *et al*. (1991) also recommend the use of more than one method to arrive at an estimate; the weak points of one method can be compensated by the strong points of another method.

### 2.7.2 ERP Cost Drivers

A cost driver is any factor that significantly affects total cost (Roy *et al.,* 2001). Since the circumstances in which a project takes place are rarely 'normal', the estimate must be refined using additional cost drivers (Equey *et al*., 2008). Roy *et al.* (2001) define two types of cost driver as; (1) quantitative which can be defined as a cost driver that can be given a precise value, and (2) qualitative which can be defined as a cost driver for which it is difficult to assign a precise value. In terms of qualitative cost drivers, a value can only be given through heuristic methods, for example, quality and complexity (Raj *et al.,* 2001). Heemstra (1992), Stensrud (2001) and Equey *et al*. (2008) define the cost drivers listed in Table 2-7.

**Table 2-7:** Cost Drivers

| Author | Cost Driver |
|---|---|
| **Heemstra (1992)** | Complexity software, Hardware volatility, Response time constraints, Quality analysis, Experience with application, Quality programmers, Hardware experience, Project duration constraints |
| **Equey *et al*. (2008)** | Number of sub-modules, Size of organization, Number of users, Number of transactions, Number of interfaces, Number of reports, Amount of data conversion, Number of user groups, Complexity of transactions, Complexity of interfaces, Complexity of reports, Complexity of data, Number of departments, Complexity of business processes, Type of modules implemented, ERP consultant's level of experience, Employee's involvement in ERP project, Management's involvement |
| **Stensrud (2001)** | Users, Sites, Business units, Software interfaces, Electronic Data Interfaces (EDI), Data conversion software and data conversions, Custom-developed reports, Modified screens, ERP modules |

Based on literature review and experience, the researcher added a few cost drivers to the above-outlined, and assigned them to cost dimensions in Table 2-8. One of the cost driver dimensions, project, is also defined as a cost driver grouping by Yu (1990).

**Table 2-8:** ERP Whole Life Cycle Cost Drivers

| Cost Dimension | Cost Drivers |
|---|---|
| **Organisation** | Number of employees, Size of company, Annual turnover, Number of users, Number of sites, Assessment of number of departments, Number of legacy applications, Number of processes, Internal issues, Acquisitions over last 1 year, Type of company, Diversity, Country, Security status, Assessment of legacy I.T. infrastructure |
| **Resource** | Level of project team experience, Status of resource, Labour cost, Cost of workforce unavailability, Backfilling cost, Hardware, Network infrastructure, Office space, Accommodation for project team, Vehicle for logistics |
| **Project** | Number of ERP vendors evaluated, Implementers evaluated, Number of third party products, Cost of negotiation, Terms of contract, Procurement processes, Travel cost, Business Process Re-engineering, Implementation planning, Hardware installation, Hardware upgrade, Configuration, Number of business processes, Training, Communication, Documentation, Change management, Data cleansing, Data conversion, Testing, Reports generation, Interfaces, Level of customisation, Third party product cost, Slow decision making, Quality of vendor support, Complexity of project, Cancellation, Change in scope, Cost of budget overrun, Schedule overrun, Contingency |
| **Application** | Number of software licenses, Database, Number of modules, Level of integration |
| **Operations** | Cost of low level of understanding of system, Cost of upgrading hardware, Cost of upgrading ERP software, Cost of upgrading third party tools, Software maintenance fee, Changes made to ERP application, Level of customization, Cost of assessing ROI, Cost of assessing end of life span, Evaluation of new software, Disruption of business |

## 2.8 Dynamic Modelling Approaches

Having analysed the various cost estimation techniques in Section 2.7.1, the researcher proceeded to study dynamic modelling approaches. The rationale behind this study was to identify a model which will enable the visualisation and simulation of the complexity cost estimation over time. According to Ali *et al.* (2014), simulation modelling is the imitation of operation of real world process or system played overtime. Barlas (1996) asserts that models fall into many different categories according to different criteria, such as physical vs symbolic; dynamic vs static; deterministic vs stochastic. The complexity cost estimation of resources in this research falls into the stochastic and dynamic model categories. Therefore, this research requires a model which will cater for the dynamic and stochastic nature of its output through visualisation. In this research, as the time spent on an activity increases, so will the complexity in the ERP project activity, which will in turn cause an increase in both the cost of the activity and the cost of the resource experiencing the complexity. This demonstrates dynamism. The complexity cost is not predictable as its increase is exponential and non-linear; hence the complexity is stochastic, which refers to variability over time. Ali *et al.* (2014) assert that simulation is a significant tool for facilitating decision making and improving processes.

The literature review conducted so far does not indicate that cost models currently exist for ERP resource complexity. However, the study of simulation as a potential method for estimating resource complexity cost in this research revealed three modelling techniques; agent-based modelling, discrete event modelling and system dynamics.

Agent-based modelling (ABM) makes a model seem closer to reality (Bonabeau, 2002). Although Jennings *et al*. (1998) and Nilson *et* al. (2006) stipulate that there is no standard definition of an agent, Jennings *et al*. (1998) define it as a computer system, located in some environment which is capable of flexible autonomous action in order to meet its design objectives. Brailsford

(2012), Siebers *et al*. (2010) and Bonabeau (2002) posit that in agent-based modelling (ABM), agents are modelled as a system which constitutes a collection of autonomous decision-making entities with interrelationships. As implied by Jennings *et al*. (1998), agent-based models may constitute one or more agents. Both multi-agent and autonomous agent systems are a new way of analysing, designing and implementing complex software systems (Jennings *et al.*, 1998). According to Bonabeau (2002) and Jennings *et al*. (1998), agents are used in a variety of applications including personalised email filters, complex systems such as air traffic control, flow simulation, organisational simulation, market simulation and diffusion simulation. ABM provides decision makers with robust and accurate what-if scenarios of the dynamic interplay among several business functions (Nilson *et al*., 2006). One modelling and simulation approach influenced by the complexity paradigm is ABM (Nilson *et al*., 2006), which suits the purpose of this research.

One of the characteristics of ABM is that each agent assesses its situation, makes decisions based on a set of rules, and may execute various behaviours appropriate for the system they represent (Brailsford, 2012; Parunak, 1998; Bonabeau, 2002). A simple agent-based model can exhibit complex behavioural patterns and provide valuable information about the dynamics of the real world environment it emulates (Bonabeau, 2002). Brailsford (2012) asserts that state is a crucial attribute of an agent model because an agent's behaviour is based on its state, and only on its state. Agents also evolve, thereby causing unexpected emergent behaviours which may also lead to nonlinear behaviours (Brailsford, 2012; Bonabeau, 2002). This attribute is suitable for this research as it is intended to demonstrate the nonlinearity of ERP complexity. Parunak *et al.* (1999) stipulates that an agent-based model constitutes a set of agents that encapsulate the behaviours of the various individuals that make up the system, and execution involves emulating these behaviours.

In addition to emergence, Jennings *et al*. (1998) and Bonabeau (2002) both agree that one of the benefits of agent-based modelling is flexibility. Bonabeau (2002) defines flexibility along three dimensions:

- Ease to add more agents to an agent-based model.
- Provision of a natural framework for tuning the complexity of the agents' behaviour: behaviour, degree of rationality, ability to learn and evolve, and rules of interactions.
- Ability to change levels of description and aggregation. ABM may be used in circumstances where the level of description or complexity is not known beforehand and will consequently require some manipulation.

Bonabeau (2002) posits that ABM looks at the organisation from the viewpoint not of business processes, but of activities which is what people actually do inside the organisation. Furthermore, stochasticity applies to agents' behaviour (Bonabeau, 2002).

System dynamics (SD) is a second simulation technique highlighted by Forrester (2006) and Buxton (2006). Forrester (2006) posit that system dynamics can accept the complexity, nonlinearity, and feedback loop structures that are inherent in social and physical systems. According to Buxton *et al.* (2006), simulation is commonly applied in the operations management discipline through discrete event modelling or system dynamics. However, according to Forrester (2006), little guidance exists for converting a real-life situation into a simulation model in systems dynamics. Many SD projects have fallen short of their potential because of failure to gain the understanding and support necessary for implementation (Forrester, 2006). It is for this reason that the researcher did not attempt to adopt SD in the cost modelling of resource complexity.

Discrete event simulation (DES) is a third modelling technique discussed by Brailsford (2012), Sieber *et al*. (2010) and Buxton *et al.* (2006). Discrete event is event and process oriented, and is operated within systems like manufacturing or service processes (Buxton *et al.,* 2006). System dynamics assumes a systems thinking view to understand the complex dynamics produced through interactions of feedback and control mechanisms using a bird's eye view (Buxton *et al.,* 2006). However, it would be challenging to capture an indepth understanding of the behaviour of different players in the market place using system dynamics (Buxton *et al.,* 2006). Hence the advent of agent-based modelling which overcomes this problem as each agent has the elements of a discrete event or system dynamics approach within it (Buxton *et al.,* 2006). Brailsford (2012) supports this view by asserting that DES is a proper subset of ABM because any DES model can be represented as ABM models which transcend the standard features in DES and require additional modelling constructs which are part of the DES toolkit. Siebers *et al.* (2010) compares ABM and DES models in Table 2-9.

**Table 2-9:** Comparison of ABM and DES Models (Adopted from Siebers *et al.,* 2010)

| DES models | ABS models |
|---|---|
| Process oriented (top down modelling approach); focus is on modelling the system in detail, not the entities | Individual based (bottom up modelling approach); focus is on modelling the entities and interactions between them |
| Top down modelling approach | Bottom up modelling approach |
| One thread of control (centralised) | Each agent has its own thread of control (decentralised) |
| Passive entities, i.e. something is done to the entities while they move through the system; intelligence (e.g. decision making) is modelled as part in the system | Active entities, i.e. the entities themselves can take on the initiative to do something; intelligence is represented within each individual entity |
| Queues are a key element | No concept of queues |
| Flow of entities through a system; macro behaviour is modelled | No concept of flows; macro behaviour is not modelled, it emerges from the micro decisions of the individual agents |
| Input distributions are often based on collect/measured (objective) data | Input distributions are often based on theories or subjective data |

A disadvantage of agent-based modelling is that the behaviour of all its constituent units is computation intensive and time consuming (Bonabeau, 2002). Furthermore, the degree of accuracy and completeness of inputs into the model vary because they are parameterised and consequently, the nature of the output is varied, ranging from qualitative insights to quantitative results usable for decision-making (Buxton *et al*., 2006; Bonabeau, 2002).

Based on the study conducted on the various modelling approaches, agent-based modelling is more suitable for this research. Firstly, as ABM supports dynamism and stochasticity, it would easily address the dynamic and stochastic nature of the resource complexity cost of this research due to its change and unpredictability. As ABM constitutes a bottom-up approach, it would model the behaviours of the individual resources based on their activities since ABM simulates activities quite naturally. DES is characterised by a top-down approach; hence it would not suit this research because the activities and resources would require individual modelling. The resources produced in this research for costing would require knowledge of the activities to which they are allocated at any point in time, as well as the subsequent activities to execute in order to reach their goal which would be the last activity. ABM is characterised by its learning and goal-oriented abilities; hence its agents can represent resources and aid them in knowing and moving around their activities through learning. This makes them active, as opposed to DES which entails passive entities. The rules of interactions in ABM would support the communication amongst the resources. As ABM is influenced by the complexity paradigm, based on the complexities encountered in ERP implementations, it can simulate the complexity cost estimation through resources as agents. Due to its emergence and evolution capabilities, agent-based modelling is suitable for managing the complexities as they emerge and for calculating the complexity cost based on certain conditions. The agents in ABM are active, whilst the entities in DES are passive. However, this research requires the resources it produces to be active.

## 2.9 Uncertainty and Risk in ERP Costing

In spite of thirty years of experience in managing software development projects, cost and schedule overruns continue to plague many organizations (Nidumolu, 1996). One key problem in completing projects on time and within budget is the uncertainty associated with software development (Nidumolu, 1996). The same can be concluded for ERP whole life cycle projects. Uncertainty is the difference between an anticipated or predicted outcome (e.g., cost estimate) and the confirmed outcome (Roy *et al*, 2009). PMI (2014) emphasise that uncertainty may increase with the number of interdependent actions, and is perceived as the inability to pre-evaluate actions. Furthermore, it is important to understand the nature of the uncertainty in estimates and the risks that arise from that uncertainty (Kitchenham, 1998). However, Kirkham *et al*. (2004) advise that the terms uncertainty and risk are often used interchangeably, although a distinction can be drawn by noting that the concept of risk deals with measurable probabilities while the concept of uncertainty does not. An event is uncertain when no probabilities can be developed concerning its occurrence (Kirkham *et al*., 2004). Parry (1996) discusses uncertainty from the perspective of probabilistic risk assessments of complex systems. Parry (1996) advises that it is becoming increasingly important to decision makers when presented with the results of a Probabilistic Risk Assessment (PRA) of the mission being performed by a complex system; the uncertainty in the results of the PRA is correctly characterised.

Uncertainty is characterised by Parry (1996), Refsgaard *et al.* (2007) and Erkoyuncu *et al.* (2011) as either being of an aleatory or epistemic nature. However, Refsgaard *et al*. (2007) refers to aleatory as stochastic. Uncertainty is aleatory when the events or phenomena being modelled are characterised as occurring in a ‘random’ or ‘stochastic’ manner, and adopt probabilistic models to describe their occurences (Parry, 1996). This aspect of uncertainty is what provides the PRA with the probabilistic part of its name. Erkoyuncu *et al.* (2011) posit that aleatory uncertainty tends to occur in the presence of tangible data, although it occurs due to system variability. On the other hand, epistemic uncertainty is associated with the analyst's confidence in the predictions of the PRA model itself, and is a reflection of their assessment of how well their model represents the system being modelled (Parry, 1996). A model is an analyst's attempt to represent a system in a form that can be used as an explanatory and an exploratory tool (Parry, 1996). Erkoyuncu *et al.* (2011) caution that epistemic uncertainty is characterised by the lack of tangible data which results in ambiguity in data due to multiple interpretations influenced by the knowledge state of the decision maker. This particular uncertainty derives from expert judgement, which is typically applied in the absence of data (Erkoyuncu *et al*., 2011). Daneva (2008) implies that ERP adopters perceive uncertainties of project context as a huge challenge as it is almost impossible for them to determine a level of trust in any estimate.

In order to provide an efficient and effective decision support in life cycle design, costing methods should have the capability to handle uncertainty (Durairaj *et al*., 2002). In situations where there is lack of information and the presence of unexpected activities, uncertainty conditions have to be used in the Activity Based Costing model because their methods are relatively easy and provide clear methodology (Durairaj *et al*., 2002).

Levander *et al* (2007) advise that there are two central contributors to uncertainty in a product development context; (i) technology novelty/complexity and (ii) project complexity. Uncertainty has also been addressed in terms of the difficulties of task performance (Levander *et al*., 2007). The more uncertain the task, the greater the quantity and quality of information is needed to generate the knowledge necessary to complete the task (Levander *et al*., 2007). In order to ascertain a good idea of the risks inherent in estimates, Kitchenham (1998) suggests the adoption of bounds. Uncertainty needs to be represented as upper and lower bounds on estimates corresponding to the 95% or 99% confidence limits (Kitchenham, 1998). Wide bounds indicate a larger degree of uncertainty, and narrow bounds indicate a well-understood project (Kitchenham, 1998).

Quantitative studies by management science scholars have shown how ERP adopters can use financial valuation techniques when it comes to evaluating investments in large ERP assets under uncertainty (Daneva, 2008). Daneva (2008) advises that in the past five years, the software measurement community proposed solutions to uncertainties be incorporated into traditional effort estimation techniques (e.g., COCOMO II) by using concepts of fuzzy logic or of probability theory. For instance, instead of using ‘data points’ as inputs into algorithmic models of effort estimation, one could consider representing uncertain inputs by using probability distributions (Daneva, 2008). These uncertain inputs are further processed by means of some simulation techniques, for example, a Monte Carlo simulation or a Latin Hypercube simulation (Kirkham *et al.*, 2004, Daneva, 2008). Daneva (2008) defines Monte Carlo simulations as a problem-solving technique which approximates the probability of certain outcomes by running multiple trial runs, known as simulations, using random variables.

Immature processes that are high-risk are likely to have cost, schedule, and quality problems; while mature processes have consistently high results because their risks are under control and the management can estimate resources more accurately, and plan and implement efforts at improving processes (Nidumolu, 1996). Tsai *et al.* (2010) advise that understanding ERP implementation risks can help reduce the failure of ERP projects. As failure is a consequence of complexity, this also means that a risk reduction effects a complexity reduction.

Risks were always an important concern in the development of software systems (Leopoulos *et al.*, 2005). One of the risks emphasised by Leopoulos *et al.* (2005) is the customisation of an ERP solution. This risk has already been flagged in this literature review as a critical failure factor and complexity in ERP implementations. Hence it is pertinent to convey that ERP complexity and risk are interrelated. Leopoulos *et al.* (2005) emphasize that an increase in ERP implementation risks is due to the increment in complexity.

### 2.9.1 Uncertainty in Activity Time Estimation

Project activities are executed according to a time period which reflects duration with a start and end date for each activity. The total duration for all the activities is the time it will take to complete the project. However, in ERP projects, this completion time often overruns. This supports Roy's *et al.* (2009) definition that uncertainty is the difference between an anticipated outcome and the actual outcome. Therefore, uncertainty is inherent in project durations. It is for this reason that the program evaluation and review technique (PERT) is applied to the estimation of project schedules. PERT is a well known technique with proven value in managing complex projects (Premachandra, 2001). According to Shou *et al.* (2000), Premachandra (2001) and Yun-Ning *et al*. (2010), this technique is used to solve the problem of uncertainty in project activities. It uses three values known as a three-point estimate to calculate the project duration for each activity (Premachandra, 2001; Shou *et al.,* 2000; Yun-Ning, 2010). A three-point estimate constitutes a pessimistic, most likely and optimistic durations (Premachandra, 2001; Shou *et al.,* 2000). Each value is calculated separately by an expert (Premachandra, 2001). The most likely duration is a weighted average. The essence of using three values is to cater for any uncertainty in the completion time of the relevant activity. Three-point estimating is used in this research in combination with PERT.

## 2.10 Research Gap Analysis

The study conducted in this chapter has revealed that it is necessary to study the definition and classification of complexity, complexity metrics and cost estimation techniques from the perspectives of ERP implementations and software development. This literature review indicates that there is a lack of understanding of complexity, and a lack of a comprehensive complexity metric and cost estimation technique for ERP implementations.

A widely accepted and standard definition for complexity does not exist in literature. Therefore, various authors have different definitions for complexity. Both structural complexity and application domain complexity have the same meaning as conceptual complexity which is defined by Phukan *et al*. (2005). The lack of a standard definition for complexity indicates that there is a lack of an indepth understanding of it. This is due to the fact that complexity possesses a variety of characteristics, which classifies it as a multidimensional construct which has no standard definition (Jacobs, 2013; Darcy *et al.* 2005). The absence of a widely accepted definition for complexity makes it difficult to understand. Therefore, for the purpose of this research, complexity is defined as the attribute of a system which makes that system difficult to use, understand, manage, implement, and/or with a potential to increase. This definition was adopted based on its attribute of difficulty which is expressed by several authors. It was adapted from Sessions' (2011) complexity definition.

This study also reveals that there is no standard classification for complexity. For instance, authors in the complexity field have classified complexity as factors, types and dimensions. However, some complexities in one of these categories appear in a different category defined by another author. Structural complexity was categorised in this study as a complexity factor and a complexity dimension. This is an indication of a lack of understanding of how complexity should be categorised. Therefore, as Karnacias *et al.* (2010) has distinctly asserted that classifying the different aspects of complexity is pertinent, this research has classified complexity into six categories. These categories are variability, variety, cognitive, functional, structural and integration according to Ribbers' (2002) and Radulescu's (2006) dimensions of complexity.

These categories have been defined for this research as a method of classifying the characteristics of complexity for a better understanding of complexity.

Most of the literature on complexity is focused on software development complexity. This kind of complexity lays a significant emphasis on the software coding metrics, of which have been proposed in literature (Bansal *et* al., 2008). However, most of these software metrics are designed for bespoke systems, and not package systems like ERP which highlights Stensrud's (2001) conclusion that prediction systems have not been defined for ERP projects. Although this deduction was made in 2001, Yindun *et al.* (2007) and Rashidi *et al*. (2010) emphasise that the concept of complexity needs to be expressed as a combination of metrics due to a lack of a comprehensive complexity measurement technique. As defined by Shao *et al.* (2003a, b), and Delugach *et al.* (1997), some of the most popular software complexity metrics discussed in this study are LOC (Lines of Code), Halstead complexity measure, IF (Information Flow), and McCabe cyclomatic measure. This limitation in a comprehensive ERP complexity metric presents a difficulty in estimating the complexity of a potential ERP implementation project.

Another crucial aspect of ERP highlighted by literature review is that there is not yet a comprehensive cost estimating technique which would be utilised in costing ERP implementations from a very early stage in the ERP whole life cycle. According to Heemstra (1992), one of the reasons for this is that clear and complete specifications are difficult to formulate at the start of a project. Stensrud (2001) stipulates that ERP projects are estimated through the application of a multi-dimensional project size measure, as there is no internationally agreed upon "project size" standard for these projects. Therefore, it is necessary to define a comprehensive cost estimating technique for ERP implementations, and a framework which would enable the cost estimation at an early stage of the project whole life cycle. This will enable an early prediction of implementation costs and reduce the current cost overruns in

ERP projects through cost control. Additionally, this study has demonstrated that complexity drives cost. As Phukan *et al*. (2005) stipulates, software complexity is the major reason for the rapid increase in software costs. Jacobs (2013) asserts that complexity is increased with a multiplicity of elements. So far, literature review does not provide any knowledge of the existence of a complexity cost estimation technique nor does it provide a framework which will enable a complexity costing process. In the absence of a technique and framework to estimate the cost of complexity, it would be a challenge for ERP adopters to anticipate the cost of a potential ERP implementation with inherent complexities. It is for this reason that organisations experience uncontrollable cost overruns. This highlights a compulsory need to estimate the cost of complexity. It also necessitates the need for a framework to cost complexity.

This literature review has illustrated that the resources deployed onto ERP systems implementations are very critical to the success of the project Hsu *et al*. (2011). It is these resources who experience the complexities which are presented in the system. Vogt (2002) posits that unanticipated difficulties are always encountered on ERP projects. According to the complexity definition of this research, difficulties are complexities. An ERP implementation cost is mostly driven by its resources and complexities. Vogt (2002) and Stefanou (2001) suggest that consulting cost is one of the hidden costs in ERP implementations, and this may prove to be a barrier to successful implementations. Therefore, the cost of the complexities in an ERP implementation should be estimated from a very early stage of the project whole life cycle, for each and every resource experiencing the complexities. This will provide a potential ERP adopting organisation with the expected costs of an ERP implementation prior to embarking on the project. The organisation will understand the complexities they will likely face, as well as the resources who will encounter these complexities. This knowledge of resource complexity cost will enable an organisation to reduce their implementation cost by controlling their resource complexity. Currently in research a model does not exist to estimate the cost of ERP complexity from a resource perspective.

The main research gaps identified through this literature review are summarised as follows:

- There is a lack of an understanding of complexity
- There is a lack of a comprehensive metric for assessing complexity
- There is a lack of a technique for estimating the cost of complexities in an ERP implementation
- There is a lack of a technique for estimating the cost of complexities for ERP project resources

## 2.11 Summary

This chapter has analysed the previous work in the area of enterprise resource planning challenges, failures, complexities, resources, project activities and costing in order to provide a better understanding of the ERP practices in relation to resource complexity costing. Various ERP system implementation critical failure factors have been identified and discussed in this chapter. The most cited CFFs according to this literature review are excessive customisation, dilemma of internal integration, and organisational, management and technical challenges. The next step in the review was to study ERP complexities which were classified into six categories; functional complexity, structural complexity, cognitive complexity, variety complexity, variability complexity and integration complexity. Additionally, forty-three complexity types were studied which were mapped to their respective complexity categories for easy management and identification of ERP complexities.

The literature review detailed in this chapter highlights that it is imperative to understand complexity and measure it to enable complexity evaluation and costing. However, in order to measure complexity, it is essential that metrics exist for this purpose. This chapter indicates that most of the complexity metrics like LOC and Halstead's Product Complexity metric are predominantly applicable to software development, and not ERP implementations. On the other hand, a number of complexity measures like Function Points, MCCabe's Cyclomatic Complexity, and Control Flow Complexity may be applied in the measurement of ERP complexity. Despite the existence of all these complexity metrics which may be suitable for ERP complexity measurement, none of the metrics is comprehensive. In addition to complexity measures, costing techniques were also studied in order to understand the range of techniques which currently exist, and which of these could be used in costing an ERP implementation with complexities. Some of the costing techniques entail cost drivers which are suitable for costing an ERP implementation and its limited number of associated complexities. An example of such costing techniques is COCOMO II, but it contains only a limited number of cost drivers which may be used to cost ERP implementation and its associated complexity. And examples of ERP-related cost drivers are number of users, number of interfaces, size of organisation, amount of data conversion, complexity of interfaces, complexity of business processes, and ERP consultant's level of experience as defined by Equey *et al.* (2008).

The various stages in an ERP project whole life cycle were studied as part of this research to enable the researcher understand which stage is the most costly and the most complex, thereby requiring the most attention. Within the most complex stage, which is implementation, the researcher would have a detailed understanding of its phases, project activities and resources. This knowledge will form the foundation for defining suitable complexity metrics for the project activities, and selecting an appropriate costing technique.

The research gaps based on the literature review conducted in this research are; (1) a costing technique does not exist to cost the resource complexity of an ERP implementation, and (2) a comprehensive metric has not yet been defined for measuring complexity. Therefore, the researcher would develop a framework to assess and measure complexity, and cost it for each resource involved in an ERP implementation.

The next chapter describes the research methodology applied in this research.

# 3 RESEARCH METHODOLOGY

## 3.1 Introduction

Prior to conducting research, it is essential for the researcher to select the correct methods for fulfilling the research. This is the process of research design. Several methods and strategies exist in research and each one applies to a certain kind of study. Hence it is imperative for the researcher to have a thorough understanding of their research concept in order to select the appropriate research design. The topics discussed in this chapter are outlined in Figure 3-1.

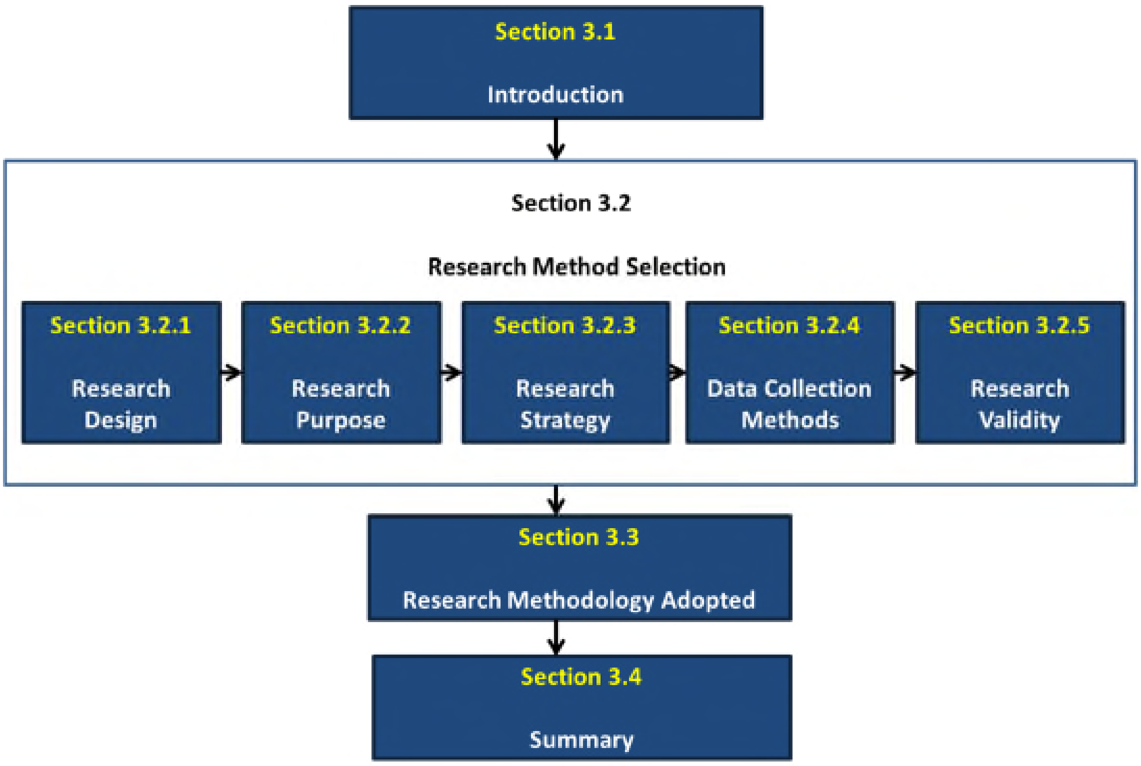



**Figure 3-1:** Outline of Chapter 3

## 3.2 Research Method Selection

The rationale behind the selection of the research methods and approaches is discussed in this section. Figure 3-2 highlights the research methods selected. The methods applied in this research are highlighted in the blue boxes in Figure 3-2.

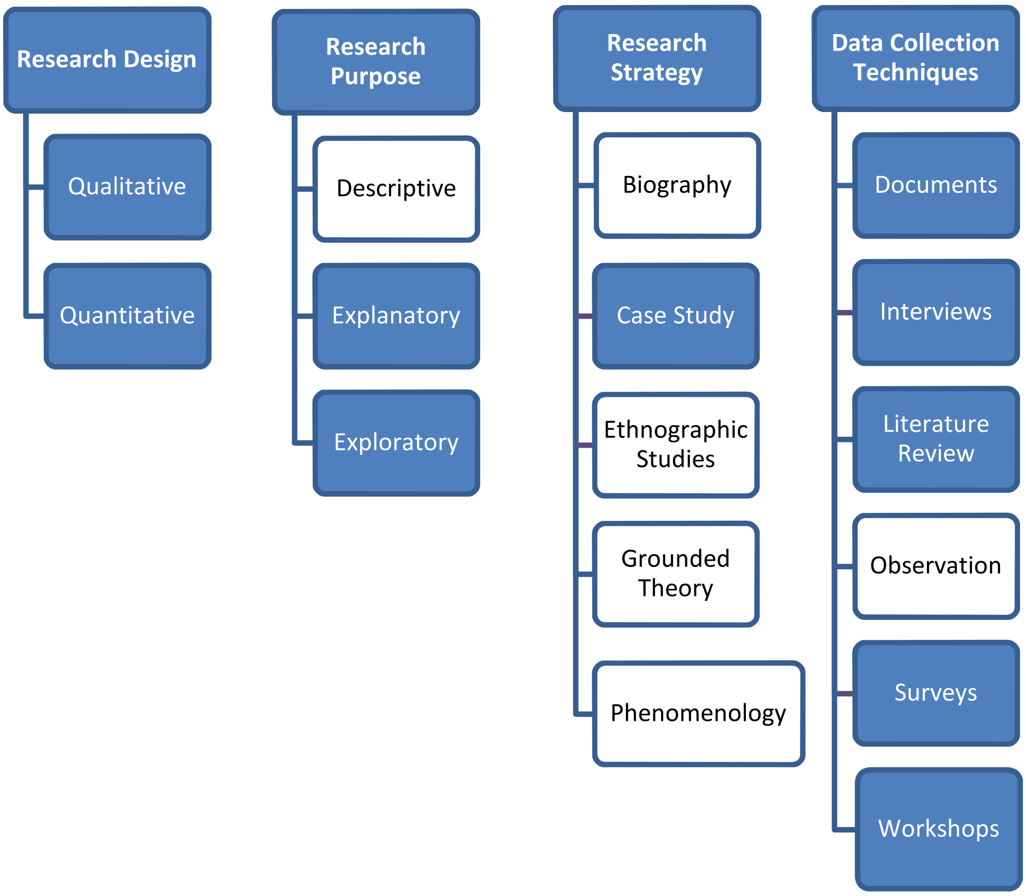



**Figure 3-2:** Research Approach Selection

### 3.2.1 Research Design

A research design is a logical plan for getting from *here* to *there*, where *here* may be defined as the initial set of questions to be answered, and *there* is some set of conclusions about these questions (Robson, 2002; Yin, 2008). Research design may also be perceived as a "blueprint" for the investigator's research, dealing with at least four problems: what questions to study, what data are relevant, what data to collect, and how to analyse the results (Yin, 2008).

There are two kinds of research design; quantitative and qualitative design (Robson, 2002; Gummesson, 1991). The former requires certainty of the research topic prior to its design, whilst qualitative design allows a much more general approach in defining the research topic.

#### 3.2.1.1 Qualitative Research

Qualitative research design enables theory-building. Most of this research is based on words (Johnson and Harris, 2002). The project starts with a single idea or problem which the researcher seeks to understand (Robson, 2001). In this kind of design, much less is pre-specified, and the design evolves and unfolds as the research proceeds (Robson, 2002; Marshall and Rossman, 1989). Hence Robson (2002) refers to qualitative research as “flexible” research design. There is little standardised instrumentation applied (Johnson and Harris, 2002). Qualitative designs entail the use of rigorous data collection procedures and multiple data collection techniques (Johnson and Harris, 2002; Robson, 2002).

Marshall and Rossman(1989), and Johnson and Harris (2002) stipulate some of the strengths of qualitative research methodology as follows:

- Research that elicits extant and tacit knowledge
- Research that elicits subjective understandings and interpretations as a result of richness of the data
- Research that delves in depth into complexities and process
- Research on little-known phenomena or innovative systems
- Research on informal and unstructured linkages and processes in organisations
- Research for which relevant variables have yet to be identified

Qualitative research takes place in the natural world, and focuses on context (Kirk and Miller, 1986; Marshall and Rossman, 1989). Hence it is intense and involves prolonged contact (Johnson and Harris, 2002). In the process of conducting the research, a high degree of engagement with the participant's environment is pivotal to the success of the research (Johnson and Harris, 2002). This research is designed to achieve a holistic view (Johnson and Harris, 2002; Marshall and Rossman, 1989). Table 3-1 illustrates the design issues inherent in qualitative research.

**Table 3-1:** Qualitative Research Design Issues

| Qualitative Research Design Issues | Author |
|---|---|
| The researcher may experience the element of surprise if the participant provides answers that deviate from the researcher's expectations. | Johnson and Harris (2002) |
| Researchers are expected to remain free of pre-conception, whilst allowing emergence in their study. The idea that people are capable of being a 'blank slate' is challenging to sustain. | Johnson and Harris (2002) |
| Due to its very nature of allowing multiple data collection procedures and techniques, data overload is not uncommon. | Johnson and Harris (2002) |
| There are fewer established norms to generate trustworthiness and quality of findings automatically than in quantitative research. Reliability is not usually addressed directly. | Johnson and Harris (2002) |
| The comparability of qualitative data is problematic; rapport with participants may vary as participants may talk with different degrees of specificity. | Fielding (2002) |

#### 3.2.1.2 Quantitative Research

In quantitative designs, the researcher approaches the project with a substantial knowledge of the research theory. Hence they are also referred to as "fixed" design by Robson (2002). Their hallmark is a pre-specification of what the researcher is going to do, and how they are going to do it; these designs are theory-building (Robson, 2002). The data collection methods are predominantly experiments and surveys (Marshall and Rossman, 1989; Robson, 2002). Significantly, tried and tested procedures are applied in this research design (Robson, 2002). As quantitative research always involves the numerical analysis of data (Johnson and Harris, 2002; Robson, 2002), it is necessary that the data are collected in a highly structured manner (Robson, 2002). Table 3-2 highlights some of the issues which have been reported for quantitative research.

**Table 3-2:** Quantitative Research Design Issues

| Quantitative Research Design Issues | Author |
|---|---|
| The researcher must always know what they want to ask of the participants and ask the right questions; the participant does not have the flexibility to volunteer or proffer additional information. | Johnson and Harris (2002) |
| Fixed designs cannot capture the subtleties and complexities of individual human behaviour | Robson (2002) |
| The researcher's study must be replicable by a third party or at another point in time by the researcher | Johnson and Harris (2002) |
| Reliability is a key issue when dealing with hypothetical constructs and their measurement; the measurement is required to produce the same answer in the same circumstances, repeatedly. | Johnson and Harris (2002) |
| Researchers using fixed design methods are at a greater physical and emotional distance from the study | Robson (2002) |
| There are often long periods of preparation before data collection and a substantial period of analysis after data collection | Robson (2002) |

The subsection to follow provides the rationale behind selecting the highlighted research designs.

#### 3.2.1.3 Rationale for Selecting Research Design

According to Robson (2002), a design cannot be simultaneously qualitative and quantitative; it could have a qualitative phase followed by a quantitative phase. The characteristics and strengths of both qualitative and quantitative research designs fulfil the aim and objectives of this research. Hence the researcher selected both these design methods.

Firstly, the current research begins with the qualitative design where the research topic on ERP implementation challenges is explored. The challenges faced as a consequence of the disorder of an implementation sequence is also particularly investigated. Although the problems faced on ERP projects are widely discussed, but the impact of implementing the modules in a disorderly fashion is rarely mentioned. It is almost as though there is a lack of awareness of this issue. Furthermore, the complexities which are encountered by ERP resources is hardly discussed. This means that both these areas are new in the research and deserve a detailed exploration. Hence, qualitative design is appropriate for this study.

Secondly, a mixture of data collection methods, are used in this study. In the instances where numerical analysis of the data collected was required, a quantitative approach was more suitable. Harrison (2002) and Johnson and Harris (2002) both agree that quantitative and qualitative research methods need not live in isolation from each other, as they can both complement each other

### 3.2.2 Research Purpose

Clarifying the purpose or purposes of research can go a long way towards sorting out the research questions (Robson, 2002). A statement of the **purpose** of the research tells the reader what the study is likely to achieve, when generally embedded in a discussion of the topic (Marshall, 1989). There are three research purposes (Gummesson, 1991; Marshall, 1989; Robson, 2002; Yin, 2008; Zikmund, 1991); Exploratory, Explanatory and Descriptive.

#### 3.2.2.1 Exploratory Research Purpose

Exploratory study is conducted to clarify the nature of problems (Zikmund, 1991). It is also used to gain a better understanding of the dimensions of a problem (Zikmund, 1991). This research is almost exclusive of qualitative research design (Marshall, 1989; Robson, 2002).

In addition to the these three research purposes, a fourth one was identified by Marshall and Rossman (1989) as follows:

- **Emancipatory** research purpose is described in Table 3-3. It is almost exclusive of qualitative research design.

#### 3.2.2.2 Explanatory Research Purpose

Explanatory research purpose is also referred to as Causal (Yin, 2008; Zikmund, 1991). Its main goal is the identification of cause-and-effect relationships between variables (Zikmund, 1991). This research purpose may be of either qualitative or quantitative research design, or both designs (Robson, 2002).

#### 3.2.2.3 Descriptive Research Purpose

Descriptive research purpose seeks to determine the answers to *who, what, when, where and how* questions (Zikmund, 1991). It is based on some previous understanding of the nature of the research problem (Zikmund, 1991). The *Descriptive* research purpose may be of either qualitative or quantitative research design, or both designs (Robson, 2002).

Each of the four research purposes is described in Table 3-3.

#### 3.2.2.4 Rationale for Selecting Research Purpose

The purpose of this research is a mixture of exploratory and explanatory for the reasons outlined in Table 3-3. This mixture fulfils the aim and objectives of the research. At the initial stages of the research, although the ERP challenges and their triggered cost increases are widely reported in research and industry, their link to complexity and project resources is rarely discussed. Hence, the research is exploratory at its commencement. As it evolves, it becomes explanatory because the correlation between complexity, resources and cost becomes more prevalent.

**Table 3-3:** Matching Research Questions and Purpose (Adapted from Marshall and Rossman, 1989)

| Purpose of the Study | General Research Questions |
|---|---|
| Exploratory:<br>To investigate little-understood phenomena<br>To identify or discover important categories of meaning<br>To generate hypotheses for further research | What is happening in this social program?<br>What are the salient themes, patterns, or categories of meaning for participants?<br>How are these patterns linked with one another? |
| Explanatory:<br>To explain the patterns related to the phenomenon in question<br>To identify plausible relationships shaping the phenomenon | What events, beliefs, attitudes, or policies shape this phenomenon?<br>How do these forces interact to result in the phenomenon? |
| Descriptive:<br>To document and describe the phenomenon of interest | What are the salient actions, events, beliefs, attitudes, and social structures and processes occurring in this phenomenon? |
| Emancipatory:<br>To create opportunities and the will to engage in social action | How do participants problematize their circumstances and take positive social action? |

### 3.2.3 Research Strategy

The three research strategies which are relevant to qualitative studies are discussed in this section. These research strategies are Case Study, Ethnographic and Grounded Theory research designs. Additional research strategies are subsequently highlighted.

#### 3.2.3.1 Case Study

A case study involves the development of detailed knowledge about a single case or a small number of cases (Robson, 2002), and is used as a means to initiate change (Gummesson, 1991). It is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin, 2008). Hence it can be complex. The desire to understand complex social phenomena drives the requirement for case studies (Yin, 2008).

#### 3.2.3.2 Ethnographic

This research strategy involves studying how a group, organisation or community live, experience and rationalise their lives and their environment (May, 2002; Robson, 2002). Ethnography is used in a variety of fields including social and cultural anthropology, education, sociology and human geography (Singh and Dickson, 2002). An ethnographic approach unveils meaning which is inaccessible through other forms of enquiry, using interpretation, interaction, context, emotion and aesthetic experience (Singh and Dickson, 2002).

#### 3.2.3.3 Grounded Theory

A grounded theory study generates theory from qualitative data collected which relates to the particular situation that constitutes the focus of the study (Partington, 2002; Robson, 2002). Table 3-4 presents the typical features of the case study, grounded theory and ethnographic research strategies as defined by Robson (2002) and other authors specified in the table. The grounded theory is especially applied in new areas where concepts to explain the situation is almost non-existent (Robson, 2002). This study entails going out into the field and collecting data (Robson, 2002).

**Table 3-4:** Typical Features of Research Strategies

| **Qualitative Research Strategy** | **Feature** |
|---|---|
| Case Study | • Selection of a single case (or small number of related cases) of a situation, individual or concern (Yin, 2008)<br>• Study of the case in its context<br>• Data collection techniques are observation, interview and documentary analysis.<br>• Can include quantitative data, though qualitative data are predominantly collected.<br>• The case study enables researchers to retain the holistic characteristics of real-life events (Yin, 2008; Gummesson, 1991)) |
| Ethnographic Study | • Selection of a group, organisation or community of interest or concern.<br>• Immersion of the researcher in the natural setting of the study<br>• Data collection technique is predominantly participant observation, but other techniques are applicable.<br>• Data collection is likely to be prolonged over time and to have a series of phases<br>• Central focus of the study will emerge and evolve as it progresses |
| Grounded Theory Study | • Applicable to a wide variety of phenomena<br>• Provides explicit procedures for generating theory in research<br>• A systematic but flexible research strategy which provides detailed prescriptions for data analysis and theory generation<br>• Data collection technique is predominantly interview-based |

#### 3.2.3.4 Other Qualitative Research Design Strategies

In addition to case study, ethnographic, and grounded theory qualitative research strategies, two others are reported by Robson (2002) as; (1) biographical research which may be thought of as being applied where the case studied is a person and the intention is to tell the person's life story, and (2) phenomenological research which focuses on the subjective experience of the individuals studied. Robson (2002) posits that these research strategies have been added to the other three because they may be useful in answering particular kinds of research question.

#### 3.2.3.5 Rationale for Selecting Research Strategy

The strategy which was selected for this research is the case study for the reasons provided above. Gummesson (1991) emphasises that although case studies vary in character according to the phenomenon studied, there are two types of particular interest; (1) the type which attempts to derive general conclusions from a limited number of cases, and (2) the types which strive to arrive at specific conclusions regarding a single case because this "case history" is of particular interest. This research took the path of the latter. The case study conducted in this research was a single case study because it had all the characteristics required to develop the theory. Additionally, according to Yin (2008), case studies have been conducted about decisions, programs, the implementation process and organisational change. This case study concerns the implementation process applied be a large organisation implementing ERP. Organisational change is the consequence of the ERP implementation, which is done as part of a program. This particular case study is further discussed in chapter 4 of this thesis.

### 3.2.4 Data Collection Methods

This section describes the various methods which have been applied in the data collection stage of this research. The researcher applied literature review

(3.2.4.1), interviews (3.2.4.2), surveys (3.2.4.3), workshops (3.2.4.4) and documents (3.2.4.5). The rationale for selecting these data collection methods is also explained.

#### 3.2.4.1 Literature Review

The literature review is a critical aspect of data collection. An analytical reading of the literature is an essential prerequisite for all research; a researcher needs to be completely familiar with their topic (Hart, 2001; Marshall and Rossman, 1991). The argument for situating a study as significant for practice should rely on a discussion of the concerns or problems articulated in the literature (Marshall *et al*., 1989). Literature review provides intellectual glue for the entire research proposal by demonstrating the sections' conceptual relatedness (Marshall and Rossman, 1991).

Literature has the following advantages: (1) provides a researcher with topics on previous or current research related to their research area (Hart, 2001; Marshall and Rossman, 1989), (2) enables the researcher to further define their research theory (Marshall and Rossman, 1989), (3) provides a platform upon which the researcher compares research findings with further literature, (4) allows the identification of gaps in existing research thereby enabling knowledge contribution to research (Hart, 2001), (5) allows the identification of gaps in industry, (6) presents the researcher with a structure which helps them to avoid some of the pitfalls and errors of previous research (Hart, 2001), and (7) enables the design of the methodology for the research in question by identifying the key issues and data collection techniques best suited to the research topic (Hart, 2001).

Figure 3-3 is an indication of the focal points of literature review.

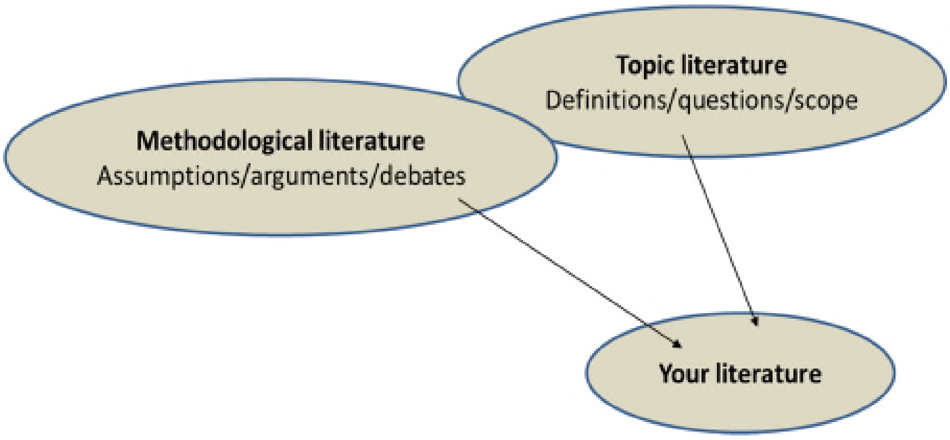



**Figure 3-3:** Two Kinds of Literature (Adapted from Hart, 2001)

Analysing the literature guides the development of explanations during data collection and analysis in studies that seek to explain, evaluate, and suggest linkages between events (Marshall and Rossman, 1989; Hart, 2001).

#### 3.2.4.2 Interviews

Interviewing is a conversation with purpose and qualitative researchers rely quite heavily on it (Marshall and Rossman, 1989). Interviews can be used as the sole or only data collection method in a study (Robson, 2002; Marshall and Rossman, 1989). In the process of the interview, the participant's perspective on the topic of interest should unfold as they view it (Marshall and Rossman, 1989). These views are uncovered with the help of the researcher by conveying a few general topics which they have explored (Gerson and Horowitz, 2002; Marshall and Rossman, 1989).

Robson 2002 define the styles of interview as follows:

- **Fully structured interview** which is predetermined with fixed questions and wording; its order is usually pre-set.
- **Semi-structured interview** which is predetermined with the flexibility to modify the order and wording based upon the researcher's perception of

what seems most appropriate. It is widely used in qualitative research design.

- **Unstructured interview** where the researcher has a general area of interest, but allows the conversation to develop within this area. It is widely used in qualitative research design.

Focus group interviewing is one of several interview methods. Robson (2002) defines it as an interview on a specific topic, which is where the 'focus' originates from. This kind of interviewing usually constitutes 7 to 10 people (although groups can range from 4 to 12) who are unfamiliar with one another, but operate in roles and environments relevant to the research (Marshall and Rossman, 1989). Robson (2002) asserts that these groups may be either homogeneous where they share a common background, or heterogeneous where they differ in background. The interviewer creates an environment where focussed questions are asked to encourage discussion and the expression of varying perspectives (Marshall and Rossman, 1989).

Individual interviews provide the opportunity to evaluate how large-scale social transformations are experienced and conveyed by the participants (Gerson and Horowitz, 2002). Therefore it is imperative that the study be conducted in the setting where all the research related complexities operate over time and where data on the multiple versions of reality could be collected (Marshall and Rossman, 1989). It is for these reasons that in-depth interviewing was selected as one of the data collection methods in this research. Also, the researcher created a focus group where she engaged a number of participants from different organisations in the research and interviewed them all at the same time in order to assess their collective perspectives and expressions on the research phenomenon and questions. These participants were also interviewed individually in order to obtain separate views that were not expressed in the group.

#### 3.2.4.3 Surveys

Surveys are difficult to define because of the number of studies that have been labelled *surveys* (Robson, 2002). Generally, surveys are a method of data collection which allows the researcher to obtain quantitative data from a number or group of individuals over a certain period of time. A *period of* time could be a single point in time for surveys involving cross-sectional measurements or at several different times for longitudinal studies (Robson, 2002; Marshall, 1989). This kind of data collection may also be used for organisations in which case data may be collected from the entire population in the company, or a sample of the population. Questionnaires are used in surveys and they are designed to ask specific questions in relation to the research area. Although surveys are mostly conducted in non-experimental quantitative designs, they can be applied in qualitative research (Robson, 2002). A typical central feature of surveys is the selection of a representative sample of individuals from known populations (Robson, 2002).

Surveys are carried out in any or all of three forms namely; mail, telephone and interviews (Marshall, 1989; Robson, 2002). These are described as follows:

- **Mail survey** involves sending questionnaires through the post to the participants, where they fill out the questionnaires by themselves and return them to the researcher by mail.
- **Telephone survey** entails the researcher interviewing the participant(s) over the telephone with the use of a questionnaire
- **Interview survey** is a face-to-face interview conducted by the researcher with the participants whom in turn fill out the questionnaires.

Marshall (1989) advises that the strength of surveys entail accuracy, generalizability, and convenience. They are also comparatively easy to administer and manage (Marshall, 1989). Despite their strengths, they also have weaknesses (Robson, 2002; Marshall, 1989). Their strengths can also be their weaknesses (Marshall, 1989). The survey data collection advantages posited by Robson (2002) are listed in table 3-5, and their disadvantages are outlined in Table 3-6 as described by Marshall (1989) and Robson (2002).

**Table 3-5:** Advantages of Surveys

| **Subject Area** | **Advantages** |
|---|---|
| Ethos | • The approach provided by surveys to the study of beliefs, values and attitudes are relatively simple. |
| Generalisability | • Surveys may be adapted to collect generalisable information from any human population |
| Privacy | • Postal and other self-administered surveys can allow anonymity, which can encourage frankness in the context of sensitive areas. |
| Data Standardisation | • Surveys provide a high amount of data standardisation |
| Data Volume and Cost | • Although Marshall (1989) posits that surveys are typically expensive, Robson (2002) emphasises that postal and other self-administered surveys can be very efficient at providing large amounts of data at very low cost, in a short period of time. |
| Interviewer Presence | • In face-to-face interview surveys, the interviewer can clarify questions.<br>• In face-to-face interviews, the interviewer being present at the interview encourages participation and involvement of the respondent. |
| Interview Time | • Telephone interviews reduce the time and resources involved in running face-to-face interviews by eradicating the travel requirements. |

**Table 3-6:** Disadvantages of Surveys

| **Subject Area** | **Disadvantages** |
|---|---|
| Complexity | • Little value for examining complex social relationships (Marshall, 1989) |
| Generalisability | • If the sampling is faulty, the findings cannot be generalised.<br>• Without further evidence, a survey cannot assure that the sample in question represents a broader universe (Marshall, 1989). |
| Cost | • Surveys are generally expensive (Marshall, 1989) |
| Privacy | • An invasion of privacy may arise (Marshall, 1989)<br>• Participants may not trust the anonymity of their answers; hence, they may be reluctant to be open (Robson, 2002). |
| Data Volume | • Surveys are sometimes perceived as generating large amounts of data often of dubious value (Robson, 2002) |
| Reliability and Validity | • Reliability and validity analysis are familiar problems of survey research (Harrison, 2002)<br>• The reliability and validity of the findings of the survey rely on the proficiency of those running the survey. Therefore, if the questions are somewhat ambiguous, the responses may be invalid (Robson, 2002).<br>• There may be interviewer bias, where they might influence the the responses (Robson, 2002).<br>• In postal and other self-administered surveys, ambiguities of the survey questions may not be detected (Robson, 2002). |
| Response Rate | • Postal and other self-administered surveys generally have a low response rate. |

Considering the advantages which are applicable to this research in Table 3-1, the researcher conducted surveys as one of her data collection methods. Other features of surveys specified above seemed appropriate enough to enable the researcher to collect from a population with individuals and organisations in the field of the research topic. This assured the researcher that the participants will respond accordingly to the questions provided in the questionnaire. The researcher also applied triangulation by encouraging both organisations and individuals to participate in answering questions on the same topic. This enabled a comparative analysis of data from various groups and individuals. A mixture of face-to-face interviews, telephone interviews and online surveys were conducted in this research.

#### 3.2.4.4 Workshops

A workshop generally involves gathering a group of individuals together to define new concepts or concepts in question. The group may be composed of people from the same organisation, different organisations, or individuals with knowledge of the topic for discussion.

Workshops were used to engage the focus groups discussed in section 3.2.4.2. Engaging the focus group in workshops enabled the researcher study their reaction to questions, which provided some form of guidance on their true feelings of the concepts being discussed. Using workshops also save the researcher a lot of time and effort on data collection.

#### 3.2.4.5 Documents

Documents are used as evidence of the findings in the data collection stage of research. They are also used as a data collection method either to support and complement other methods, or in the absence of other methods. In the event that they are used to collect data, the contents of the document are quantitatively analysed. This is known as content analysis, which is a research technique for making replicable and valid inferences from data to their context (Robson, 2002). Reliability and validity which are discussed in section 3.2.5, are central concerns in content analysis (Robson, 2002).

In this research, documents were used to; (1) support the findings of the case study, and (2) define the activities in the Work Breakdown Structure which is used to cost the resource complexities. The latter will be discussed in more detail in chapter 5 of this thesis.

#### 3.2.4.6 Rationale for Applying Multiple Data Collection Methods

The researcher used multiple data collection methods in this research. The approach to individual sources of evidence is not recommended for case studies (Yin, 2008). A major strength of case study data collection is the opportunity to use various sources of evidence (Yin, 2008). This is known as triangulation (Robson, 2002; Yin, 2008). There are several kinds of triangulation as suggested by Robson (2002). In the case of this research, data triangulation is applied. It is the use of more than one method of data collection, but aimed at corroborating the same fact or phenomenon (Yin, 2008; Robson, 2002). Triangulation can assist in countering all of the threats to validity (Yin, 2008; Robson, 2002). It can serve as the critical test, by virtue of its comprehensiveness, for competing theories (Harrison, 2002). It is for these reasons that the researcher applied triangulation in this research. All the data collection methods which have been discussed in this section were adopted by the researcher.

### 3.2.5 Research Validity

The meaning of the validity of qualitative research concerns its accuracy, correctness or trustworthiness (Robson, 2002). The trustworthiness of qualitative research design findings are of much debate (Robson, 2002). There are four tests relevant for judging the quality of research design; construct validity, internal validity, external validity, and reliability (Harrison, 2002; Yin, 2008).

The four validity tests are described below:

- **Construct Validity**: this identifies the correct operational measures for the concepts being studied (Yin, 2008; Harrison, 2002).
- **Internal Validity**: this applies in establishing a causal relationship whereby certain conditions are shown to lead to other conditions as distinguished from spurious relationships (Yin, 2008; Harrison, 2002).
- **External Validity**: defining the domain to which a study's findings may be generalised (Harrison, 2002; Yin, 2008).
- **Reliability**: this is the fourth test for judging the validity of a research study. It is aimed at minimising the errors and biases in a study (Yin, 2008). Reliability demonstrates that the data collection procedures used in a study can be repeated with the same results (Kirk and Miller, 1986; Yin, 2008; Harrison, 2002). In qualitative designs, researchers need to concern themselves with the reliability of their methods and research practices, and one way of achieving this is through an audit trail (Robson, 2002). Reliability in quantitative designs is fulfilled with the use of standardised research instruments (Robson, 2002).

The next section illustrates the methodology which was adopted for this research.

## 3.3 Research Methodology Adopted

The research design, research purpose, research strategy and data collection techniques which have been applied in this research were identified and justified in the previous section. This section presents the research methodology adopted. The research methodology entails the application of the various research approaches which have been discussed in the previous sections of this chapter. There are three phases in the research methodology which was adopted, and these are described in Figure 3-4. These phases are: (1) Phase 1: Understanding Context and Current Practices; (2) Phase 2: Framework and Tool Development; and (3) Phase 3: Framework and Tool Validation.

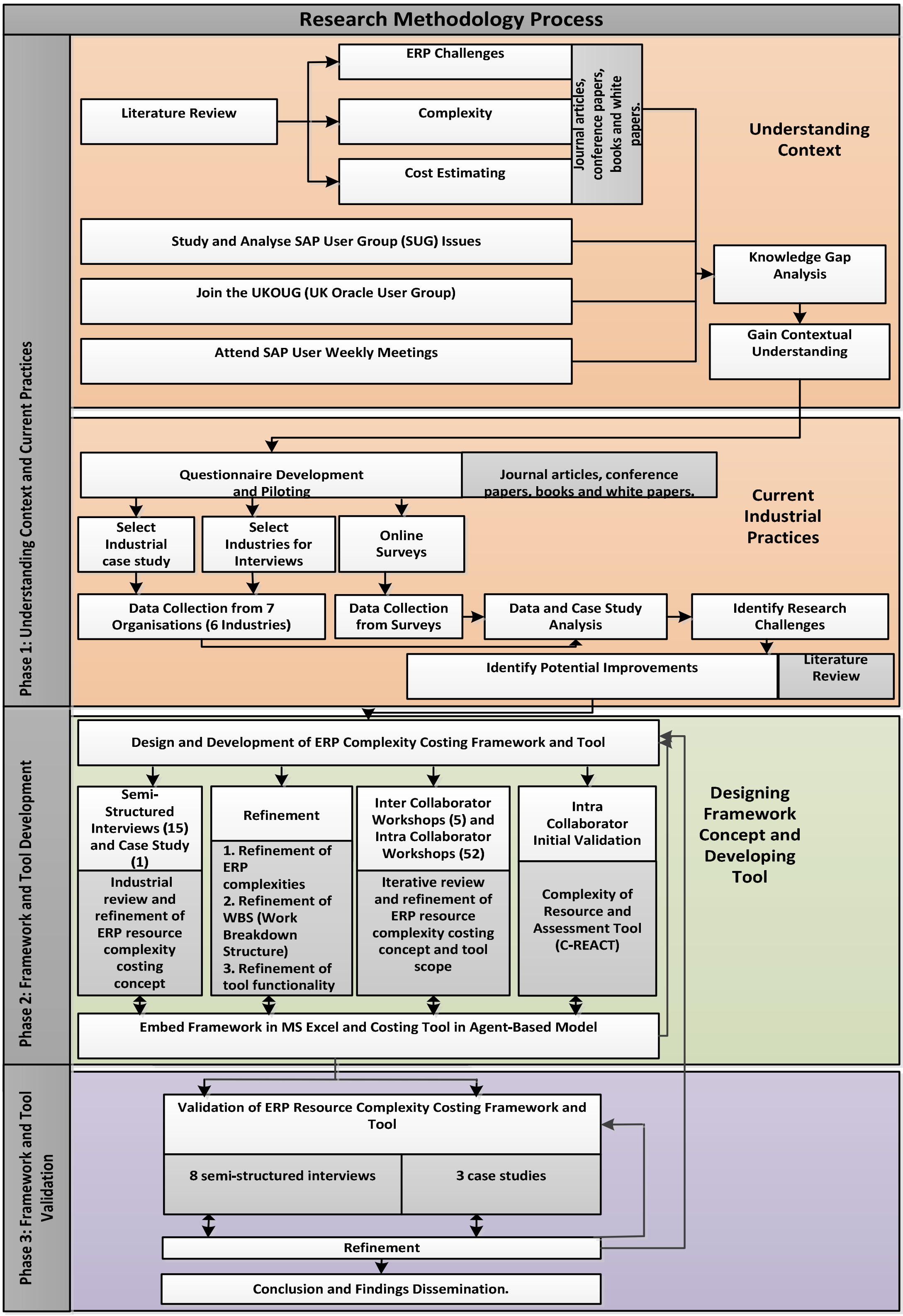



**Figure 3-4:** Research Methodology Adopted

### 3.3.1 Phase 1 - Understanding Context and Current Practices

The first phase involved gaining a contextual understanding of the research topic, research protocol development, and capturing the current practices in ERP implementations in relation to challenges encountered. A detailed literature review was conducted, starting with a classification of papers according to research objectives. The literature review covered ERP implementation challenges, stages of an ERP whole life cycle, ERP implementation methodology, dimensions of ERP complexity, ERP whole life costing, and uncertainty in an ERP environment. Some of the key journals studied in this phase are the IEEE Transactions on Software Engineering, The Journal of Enterprise Information Management, Decision Support Systems, Industrial Management & Data Systems, Computers in Industry, and Journal of Business and Management.

In the study of ERP complexity, the key target was the identification of the various complexities which affect an ERP implementation and increase its cost. The UK Oracle User Group (UKOUG) meetings and bulletins, and the analysis of SAP User Group (SAP UG) issues also assisted the researcher in identifying ERP complexities. The researcher's indepth experience in SAP also contributed to a large extent in understanding the complexities that cause ERP implementation failures and cost overruns.

As regards the ERP whole life cycle costing, the major target was the identification of cost estimating methods, techniques and cost drivers which are applied in costing ERP complexities in the implementation stage.

In order to identify the industrial current practices, four questionnaires were developed by preliminary knowledge gap analysis. These questionnaires were used to conduct and facilitate the industrial case study and surveys which involved seven different organisations from six industries; Oil and Gas Upstream and Downstream, Manufacturing, Banking, Entertainment, Public Sector, and Transport. A freelance SAP consultant was also interviewed.

A total of 43 participants were involved in the face-to-face and telephone interviews, online surveys and case study which were conducted. These interviews and case study involved SAP functional consultants, project managers, departmental heads (Procurement, Human Resources, and Finance), CIOs (Chief Information Officer), project coordinators, an Information Technology specialist and project sponsors.

The interviews and case study were analysed through triangulation. The case study findings were compared to the findings from literature review by cross-checking the complexities inherent in the case study organisation against those reported in the literature review in Chapter 2. Some of the case study results were found to exist in literature, and the others had not been identified in literature. The results provided an indepth perspective and understanding of the current issues in ERP implementations, areas requiring potential improvement and the role of ERP resource complexity costing for ERP implementations.

### 3.3.2 Phase 2 - Framework and Tool Development

The previous phase involved understanding the context of current ERP implementation issues and practices. The identification of these issues led to discovering the need for an ERP resource complexity costing framework. Phase 2 involved the Identification of the data and variables which would be required to develop and embed the ERP resource complexity costing framework in a software tool.

Having designed the framework, the researcher approached industrial collaborators from five organisations to conduct a preliminary validation of the framework concept. This process entailed reviewing the initial version of the framework concept, and refining it through semi-structured questionnaires and workshops. Two key questionnaires were used to validate and refine the concepts for (1) the WBS used for project scheduling which drives the activity duration and resourcing, and (2) the complexity identification and cost drivers. One of the companies provided the SAP project methodology which is used in their organisation to plan implementation projects. This methodology is used in the ERP resource complexity costing model.

In total, fifty-two individual workshops were held, and five focus group workshops which involved all the participants from the different companies. One case study was used to validate the final version of the conceptual design. The data from this case study serves as the defaults in the ERP resource complexity costing tool.

The outcomes from the regular meetings held with the industrial collaborators were influential in developing the framework as the product of this research.

### 3.3.3 Phase 3 – Framework and Tool Validation

A conceptual validation process was undertaken for the concepts of the framework. Collaborating organisations from industry were involved in this process. A further validation was conducted for the complexity of resource and assessment costing tool which was validated with three case studies and eight experts. The organisations in the case study are from the banking, aerospace and electronics industries. The purpose of the validation was to ensure that the tool is suitable for assessing ERP implementation complexities, and is applicable in industry. Additionally, the organisations validated the tool in order to compare the results with their original cost estimates for correctness. Furthermore, eight experts validated the tool.

## 3.4 Summary

This chapter describes the research methodology which was adopted in understanding the issues and complexities inherent in ERP implementations, discovering the need for a framework to cost these complexities, and developing the framework and the software tool within which it is embedded. The research methods which have been applied in enabling the methodology were outlined as the research design, purpose, strategy, and data collection methods.

The two research designs which were selected for this research are qualitative and quantitative designs. In order to fulfil these designs, the research purposes selected are exploratory and explanatory. The research strategy which was applied in this research is the case study approach. A mixture of data collection methods were used in this research; documents, literature review, online surveys, interviews and workshops. A rationale for selecting each of the research approaches and data collection methods was presented.

Finally, the research methodology was illustrated and described. It composes of three phases; (1) Understanding Context and Current Practices, (2) Framework and Tool Development, and (3) Framework and Tool Validation.

# 4 CURRENT INDUSTRIAL PRACTICE

## 4.1 Introduction

The previous chapter presented the research methodology adopted for this research. The case study research strategy was chosen as it fulfils the research aim and objectives. This chapter presents the case study which was undertaken to establish the current ERP industrial practice. It fulfils the research objective to investigate the complexity factors inherent in ERP implementations which will define a complexity taxonomy that enables the identification of complexities for resource complexity assessment and cost estimation. Figure 4-1 presents the outline of this chapter.

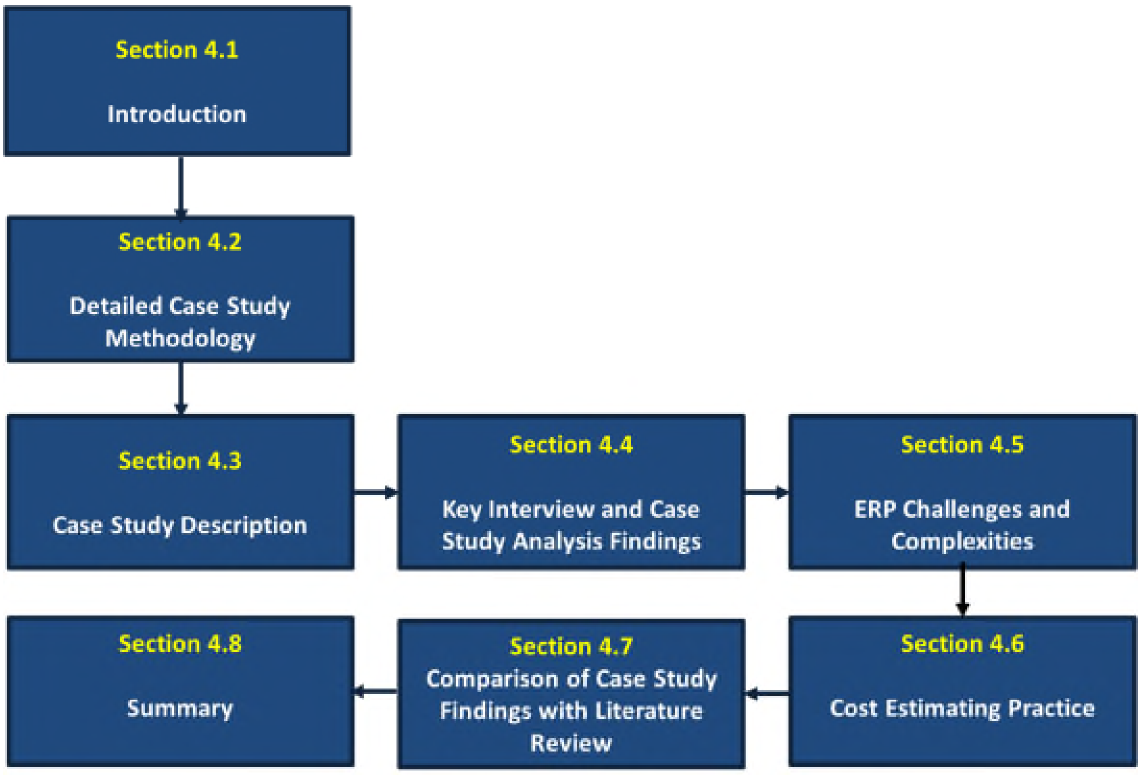



**Figure 4-1:** Outline of Chapter 4

## 4.2 Detailed Case Study Methodology

A structured methodology was adopted in conducting the case study. This is illustrated in Figure 4-2. The process started with a Case Study Anaysis (activity 1), where Company O provided a description of the SAP system implementation which they were conducting.

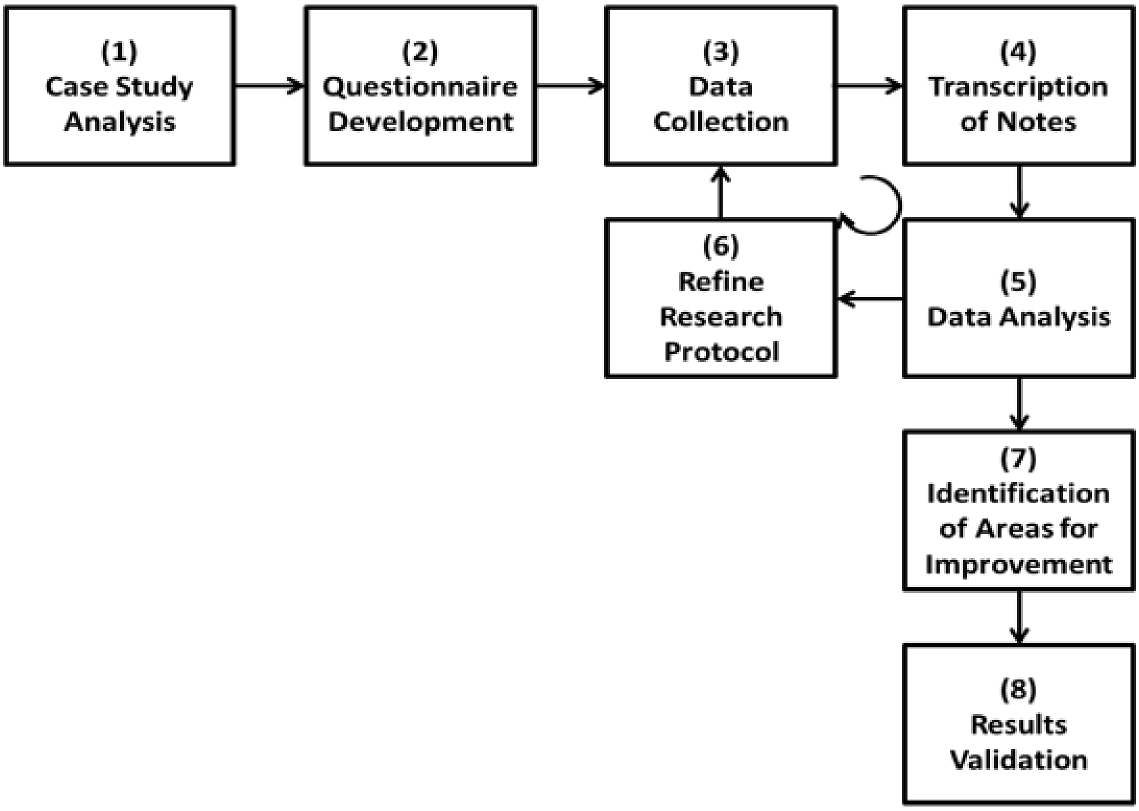



**Figure 4-2:** Detailed Methodology for Case Study and Interviews

A semi-structured questionnaire was developed (activity 2) and used to conduct face-to-face interviews with the top and middle management personnel, project sponsor and power users of the system in activity 3. They were all involved in the initial implementation as project managers, implementation auditors and subject matter experts. There were 11 participants involved in the interviews, from the Finance, Procurement, Human Resources, Payroll and Auditing departments. The current roles of the participants, as well as the roles they played on the implementation project are presented in Table 4-1. The roles are indicated in order of the interviews conducted. A wide range of expertise was sought and utilised in the interview process, which enabled the collation of very pertinent information provided on both a strategic and detailed level.

In total, 14 meetings were conducted, as three of the interviewers were visited on two different occasions. Out of all the 14 interviews conducted, nine were tape-recorded, and two were autographed.

Information was also gathered using other data sources, including project closure reports provided by the interviewees to corroborate their presentation of the challenges faced. Observation was also used as part of the data collection methodology.

Once data was collected from the interviews and case study, the notes from the interview were transcribed in activity 4 and analysed in activity 5. In some of the interviews, the researcher filled out the questionnaires on behalf of the participants, as they spoke. In other interviews, participants filled out the questionnaires. The researcher used the notes transcribed from the recorded interviews to update the questionnaires accordingly. Some of the data collected led to the refinement of the research protocol in activity 6. In the data analysis process, the researcher identified areas for improvement in activity 7. In some cases, the researcher revisited the participants face-to-face and by email, in order to validate the results of the interview in activity 8.

**Table 4-1:** Roles of Participants in Case Study

| Role in Organisation | Department/Function | Role on ERP Project | Years of Experience |
|---|---|---|---|
| **Project Sponsor** | Group Project (Mode 1) | **Project Manager** | **22** |
| **Head of Business Planning** | Finance (Mode 1) | **Key User and Subject Matter Expert** | **26** |
| **Head of SAP Competence Centre** | Competence Centre (Mode 1) | **Project Manager (Human Resources) and Business Lead** | **16** |
| **Head of Performance & Systems** | Group Services Directorate (Mode 1) | **N/A** | **25** |
| **Director of Internal Audit** | Group Audit (Mode 1) | **Project Auditor** | **22** |
| **Director of Group Procurement** | Group Procurement (Mode 1) | **Project Sponsor (Procurement)/Subject Matter Expert and Key User** | **30** |
| **Director of Finance** | Mode 2 | **Project Manager (Finance and Human Resources)** | **23** |
| **Business Operations Manager** | Group Communications (Mode 1) | **Programme Manager** | **28** |
| **Group Director HR** | Group Human Resources (Mode 1) | **Project Sponsor** | **30** |
| **Procurement Manager** | Mode 3 | **Project Manager (Procurement)** | **12** |
| **Customer Services Manager** | **Human Resource Services (Mode 1)** | **Steering Committee Member** | **15** |

## 4.3 Case Study Description

The aim of the case study is to discern the existing issues with phased ERP implementations. The case study fulfils the research objective to establish the challenges and complexities encountered in an ERP implementation. It also identifies: (1) the fundamental causes of ERP implementation challenges, and

(2) the key challenges encountered as a consequence of the implementation sequence.

The case study was conducted in a large transport organisation, Company O. This company composed of a number of other companies, known as modes. Three of these modes were the focus of the case study. Therefore a cross-case study was performed using semi-structured interviews and observations. Gummesson (1991) posits that if a researcher has a good descriptive or analytical language by means of which they can really grasp the interaction between various parts of the system, the possibilities to generalise from a few case studies, or even one single case study, may be reasonably good. The possibilities to generalise from a single case are founded in the comprehensiveness of the measurements which makes it possible to reach a fundamental understanding of the structure, processes and driving forces (Gummesson, 1991). Whilst the case study was done across the various modes, it was also conducted systematically. Its findings were analysed and reported in a holistic manner. A study where the concern remains at a single, global level is reported as holistic (Robson, 2002). However, Gummesson (1991) argues that case study which is conducted in a holistic way is time-consuming and not always possible to perform more than one or a very limited number of in-depth case studies in a research project.

Company O was a familiar organisation to the researcher, as she had previously worked on one of their projects. She observed that the organisation had undergone a substantial amount of challenges as a consequence of their SAP implementation. The majority of the ERP challenges reported in literature, as well as by practitioners, had emerged during and after the SAP implementation in Company O. These challenges had resulted in a significantly high implementation cost. More resources were deployed onto the project thereby increasing the project cost. Some challenges were also introducing other challenges. Consequently, the project schedule overran as well. Company O is a very large organisation, which was also in the process of acquiring another organisation at the time of the implementation. It already had a number of other legal entities. They had chosen an unfavourable time to implement SAP. It was for all these reasons that the researcher selected this organisation for a case study which would demonstrate the current industrial ERP practices through the challenges experienced in their implementation. Company O exhibited all the characteristics of an organisation that had encountered the ERP challenges which were stipulated in research and industry, as critical failure factors. Robson (2002) states that finding a case which fits, and demonstrating what has been predicted, can give a powerful boost to knowledge and understanding. Furthermore, as posited by Marshall (1989), closeness to the people and the research phenomenon through intense interactions provides subjective understandings that can greatly increase the quality of qualitative data. This was a realistic site for the researcher.

Marshall (1989) defines a realistic site as a place where (1) entry is possible; (2) there is a high probability that a rich mix of the processes, people, programs, interactions, and structures of interest is present (Gummesson, 1991); (3) the researcher is likely to be able to build trusting relations with the participants in the study; (4) the study can be conducted and reported ethically; and (5) data quality and credibility of the study are reasonably assured.

The transport organisation, comprised of a variety of disparate applications, each performing a separate function. Hence, they identified the need to replace their legacy systems and implement an ERP solution. Concurrently, the organisation started its merge with another company. In the process of merging, the driver for an ERP solution soon evolved into the need for business process integration across the new group and functions. Another key driver was the need to achieve transparency and to streamline business processes across functions and modes, in order to achieve commonality and uniformity in processes and policies.

Once the transport organisation had confirmed their key drivers for an ERP system, they embarked on an ERP implementation using SAP R/3.

The implementation was conducted in three modes; Mode 1, Mode 2, and Mode 3. The functions for which SAP was implemented are Finance, Procurement, Human Resources and Payroll. Although the implementation was phased across the above three modes, the same modules were implemented across the board. These modules are SAP-FI (Finance), SAP-MM (Materials Management), and SAP-HR (Human Resources) which incorporates submodules for Payroll and Shift Planning. One project sponsor was elected to run the project for all three modes.

Finance and Procurement were implemented in three phases; they were deployed to Company O Corporate in April 2003, Mode 1 in June 2003 and rolled out to Mode 2 in October 2003. The Human Resource module went live using a big bang approach in December 2003. Therefore, the phased implementation was operated at both a company and a modular level.

A number of critical challenges were faced by the implementing modes during and after implementation. One of the consequences of this was a substantial budget overrun of approximately £2 million. The initial implementation cost was estimated as £2 million. This overrun was mostly introduced by implementing the modules in an unorderly sequence.

The key questions asked during the interviews at Company O are illustrated in Figure 4-3. The answers to these questions enabled the researcher to fulfil some of the research objectives. These interview questions are:

- What drove the need for an ERP solution?
- What was the implementation approach?
- How was the implementation sequence determined?
- Which modules were implemented and in what order?
- What were the challenges caused by the phased approach?
- How were the above challenges overcome?

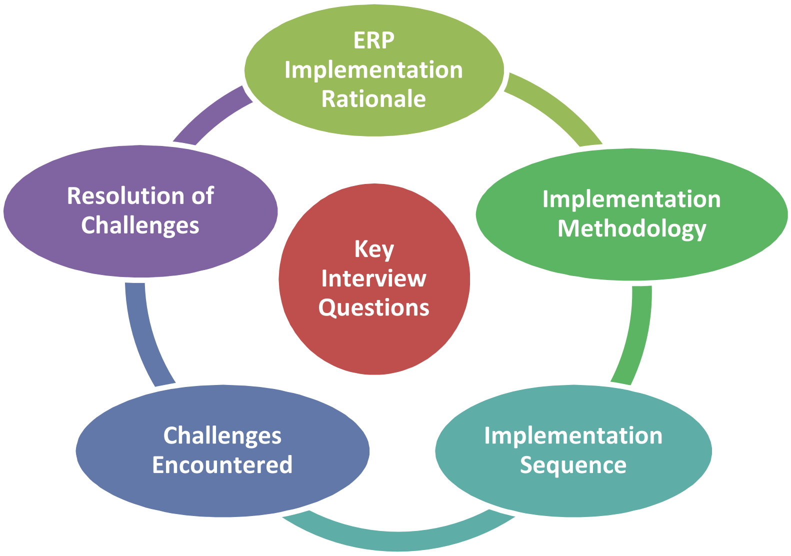



**Figure 4-3:** Key Interview Questions for Case Study Interviews

## 4.4 Key Interview and Case Study Analysis Findings

During implementation, a number of challenges were encountered, some caused as a result of the implementation sequence, and the majority erupted for a variety of other reasons.

All the challenges reported by Company O are split into three categories as follows:

(i) Challenges faced during implementation

(ii) Challenges faced after implementation

(iii) Phase-specific implementation challenges

### 4.4.1 Challenges Faced during Implementation

This section highlights the challenges which were faced during the ERP implementation across the board in Company O Mode 1, Company O Mode 2 and Company O Mode 3. Figure 4-4 presents an illustration of the challenges.

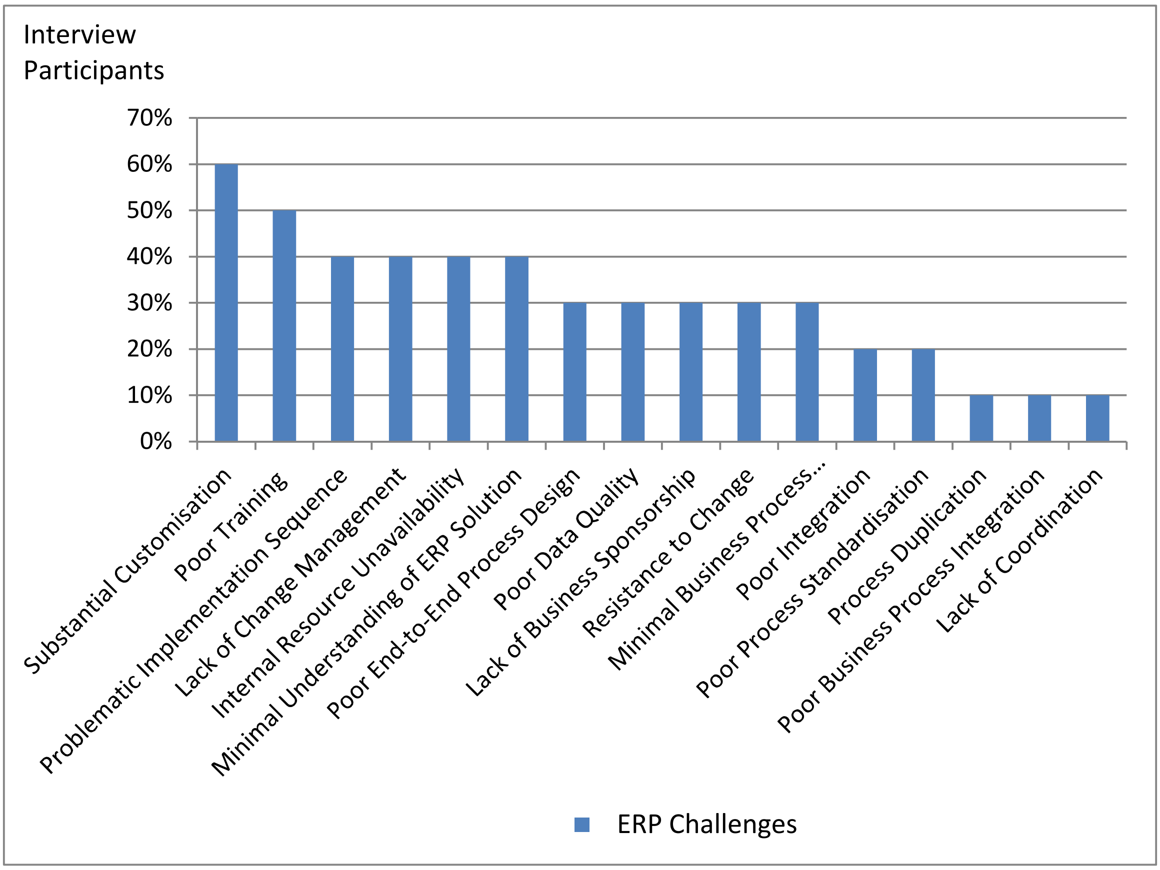



**Figure 4-4:** ERP Challenges Faced During Implementation

The top six challenges encountered during implementation are substantial customisation, lack of change management, problematic implementation sequence, internal resource unavailability, minimal understanding of ERP solution, and poor training (reported by 50% of the interview participants), as shown in Figure 4-4. Except for substantial customisation and poor training, the other four aforementioned challenges were reported by 40% of the interviewees. The biggest challenge encountered across the board in all three modes, is substantial customisation which was reported by 60% of the interview participants. Over 50% of the system deliverables were customised. In terms of the other challenges encountered on average across the modes, 30% of the interviewees reported a poor end-to-end process design, poor data quality, lack of business sponsorship, resistance to change (buy-in was not achieved by the Operations area of Mode 2), and minimal understanding of business processes. Momoh *et* al. (2010) and Alshawi *et* al. (2004) argue that data accuracy is an issue in the sense that if the data that goes into a system is not accurate or immediately accessible, the whole system becomes suspect. Other challenges presented are poor integration and a lack of process standardisation which were reported by 20% of the interviewees. And the challenges experienced on the lower end of the scale are: process duplication, a poor business process integration and lack of coordination as reported by 10% of the interview participants.

The customisation in the ERP solution was due to scope creep, an underestimation of the scale of work required for implementation, and the introduction of old practices into the new system (Momoh *et al.*, 2007).

### 4.4.2 Challenges Faced after Implementation

This section illustrates the challenges faced after implementation in Figure 4-5. As depicted in Figure 4-5, the top three challenges which were encountered by Company O after implementation, were reported by 40% of the participants as: resistance to change (the users continued to work in the same way which they did before the system was implemented), data disparity (spreadsheets were still in use and they had three financial charts of accounts instead of one), and cost overruns due to substantial customisation and project delays.

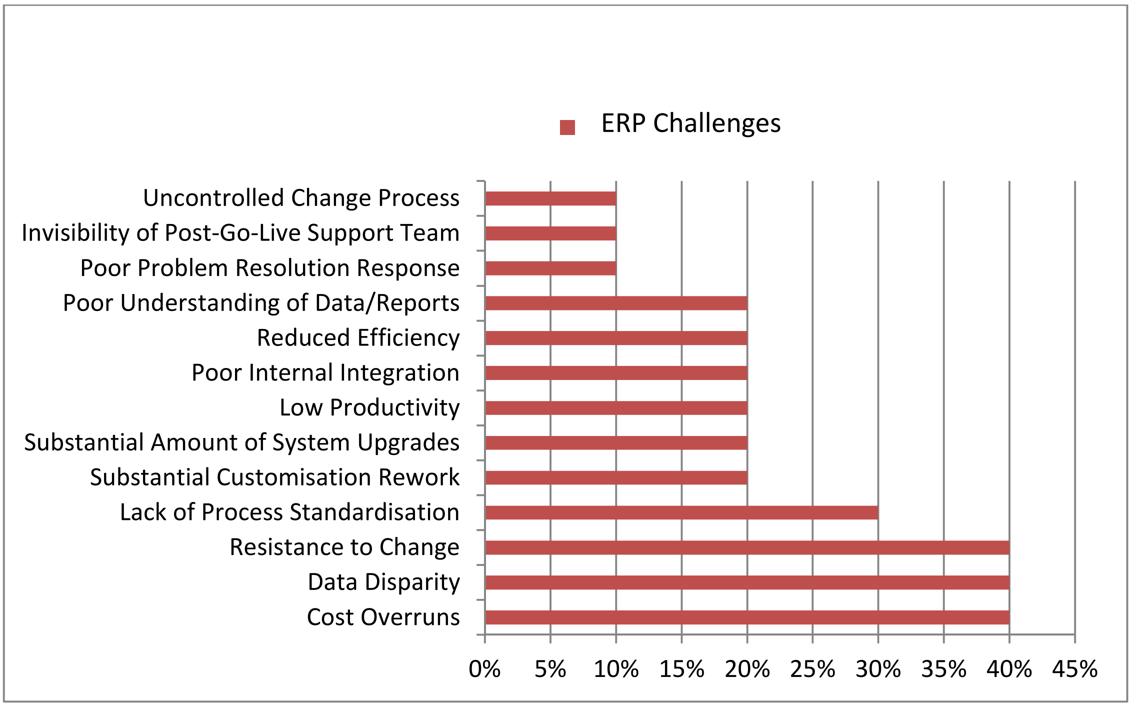



**Figure 4-5:** ERP Challenges Faced After Implementation

Resistance to change was due to poor training, which was reported as one of the challenges faced during implementation (Momoh *et al.*, 2007). The next level of challenges which were faced on average were reported by 20% of the respondents as: poor internal integration as a result of data disparity and poor process misalignment, reduced efficiency and low productivity due to limited training, poor understanding of how to extract data and reports from the system, a substantial amount of system upgrades and customisation rework. A lack of process standardisation was reported by 30% of the interviewees. The three challenges which were reported on the lowest scale by 10% of the respondents are: poor problem resolution response, invisibility of post go-live support team, and uncontrolled change processes and procedures.

The poor understanding of reporting and data extraction experienced after implementation was caused as a result of the lack of training (Momoh *et al.*, 2007). Momoh *et al*. (2007) also reported that the other challenges caused by the amount of customisation in the new system are; (1) substantial customisation rework, (2) a substantial amount of system upgrades, and (3) poor internal integration.

### 4.4.3 Phase-Specific Implementation Challenges

One of the initial objectives of this case study is to identify the implementation problems caused as a result of the sequence adopted. Hence, a different challenge category was carved out for this purpose. During the interviews with the transport organisation, 40% of the participants reported that some of the problems they encountered were caused as a result of a lack of attention to the critical factors that need to be applied in a phased implementation. One of these challenges is the implementation sequence adopted. Figure 4-6 illustrates these challenges.

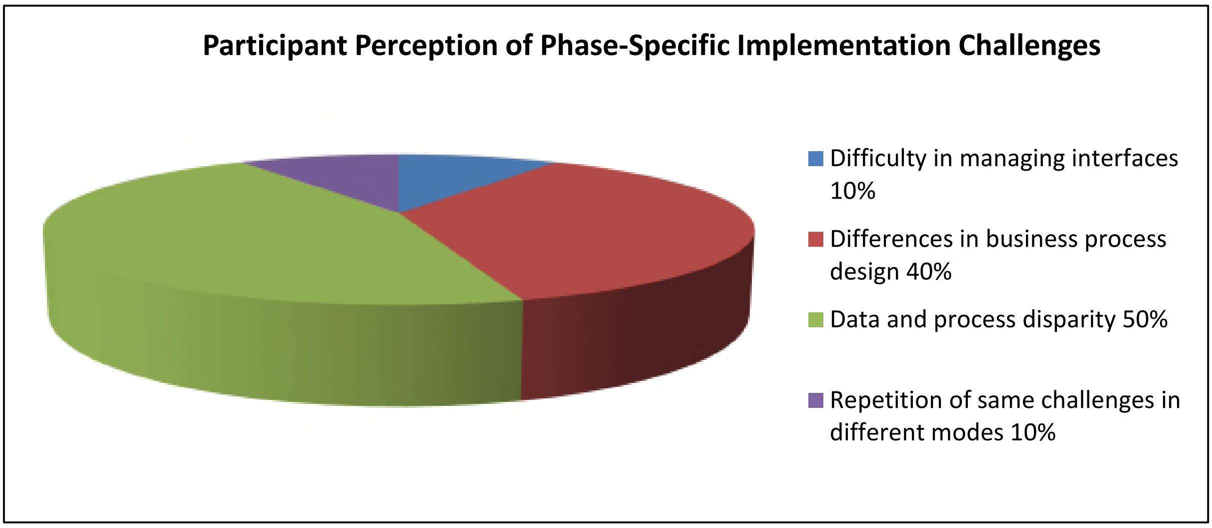



**Figure 4-6:** Phase-Specific Implementation Challenges

#### 4.4.3.1 Differences in Business Process Design

Prior to SAP being deployed to three different modes in Company O, each of these modes existed as a separate legal entity. Therefore, their Finance and Procurement processes were different and unique to each entity. However, during the implementation of SAP, these processes were neither streamlined nor standardised. For each mode, the SAP-Finance and Procurement modules were deployed to suit its corresponding Finance and Procurement processes. Hence, these processes were disparate. Consequently, the Finance and Procurement functions in all three modes worked differently in practice even though their processes should be standard across all functions.

#### 4.4.3.2 Data and Process Disparity

Although interdependencies existing between processes and functions were defined, they were poorly applied. Furthermore, due to a lack of end-to-end process design across all modes and functions, the process interdependencies were not completely identified. Hence using these interdependencies to drive the implementation sequence was a challenge. One of the causes of this challenge was due to people feeling threatened by the prospects of the implementation. There were changing behaviours. The users from the Finance, Procurement, Human Resources and Payroll functions were reluctant to share and reveal their process interdependencies with other functions. Hence, the implementation sequence was adopted with a lack of attention to the interdependencies existing amongst all the processes. Therefore, the organisational structures existing in all three functions were not streamlined. Consequently, three organisational structures were implemented, and were manually maintained at the time of the case study. This misalignment has cost Company O approximately £250,000. Should detailed attention had been paid to the interdependencies existing in all the implemented functions, the implementation sequence would have been implemented differently and correctly. The organisational management aspect of the Human Resources module would have been implemented before the Finance and Procurement modules; Human Resources is where the main organisational structure of a company is implemented, and this should ideally drive the cost centre structure in Finance. Furthermore, the Human Resource structure should drive the purchase order approval structure in the Procurement module. Plans were in place to align the three disparate structures at the time of the interviews.

#### 4.4.3.3 Difficulty in Managing Interfaces

In conducting the interviews with Company O, it was continually emphasised by the participants that there was a lack of process interdependency design. This impacted the design of the external interfaces running into SAP. Two modules that suffered from a difficult interface process are Finance and Payroll. These two functions are heavily dependent on each other. The practice in every organisation with a Payroll and Finance system, be it manual or not, is to periodically post the employee payments into Finance. The salaries are part of the company's expenditure, and must be accounted for in Finance, in order to balance the company accounts. Additionally, all National Insurance (NI), Tax and Pension contributions owed to the respective authorities must be posted into finance from payroll. In the absence of the amounts that should be paid to these authorities, organisations will not be able to pay employee taxes. This in turn, has a ripple effect on the organisations in this situation. Should they fail to pay NI and taxes by a certain date, they must pay penalties to the tax authorities. These interdependencies must be accounted for when implementing Finance and Payroll in a phased manner. Should one of these modules be implemented before the other, interfaces will be built in order to link them. These interfaces must be properly designed and are always driven by the interdependencies defined. In Company O, there was very little attention paid to these interdependencies. Consequently, the interfaces between the external payroll system and the SAP-Finance system were not well-defined. Hence, it was a struggle maintaining the interfaces. This had a huge impact on the transport organisation.

#### 4.4.3.4 Repetition of Same Challenges in Different Modes

And finally, Mode 1 had looked forward to learning from the mistakes made by Company O Corporate as the latter was deployed before the former. Unfortunately, Company O Corporate was more engrossed in transferring their implemented system into a production environment where their processes will be operational; they had very little time to share their experiences with Mode 1. Consequently, the challenges that had been experienced in Mode 1 were repeated in Mode 2. Had knowledge of these challenges been transferred to the latter mode, they could have prevented the challenges which they experienced. The end result is that Mode 2 faced numerous problems and resisted change to a great extent as a result of these challenges. A substantial amount of money was being spent in resolving these issues at the time of the interviews.

Figure 4-7 depicts the causes of the phase-specific challenges which have been discussed so far.

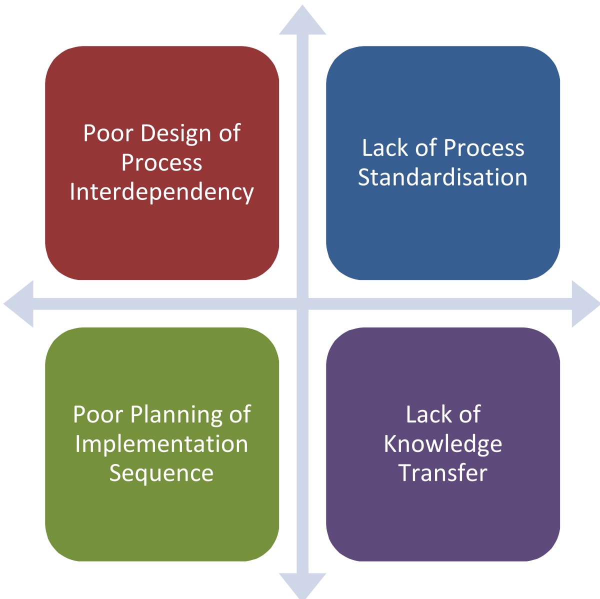



**Figure 4-7:** Causes of Implementation Challenges

The causes of the implementation challenges as highlighted in Figure 4-7 are:

- Poor design of process interdependencies
- Poor planning of implementation sequence
- Lack of process standardisation
- Lack of knowledge transfer

From the researcher's industrial experience, each of the causes of implementation challenges is a critical failure factor. Each of these factors is a major area in every ERP implementation which must be addressed critically.

As indicated in Figure 4-8, poor design of process interdependency and poor planning of implementation sequence both contribute to data and process disparity. These two causes are also correlated. In the event that the interdependencies are not well defined, the implementation sequence will most likely produce inaccuracies. Interfaces were also difficult to manage due to the poor design of process interdependency.

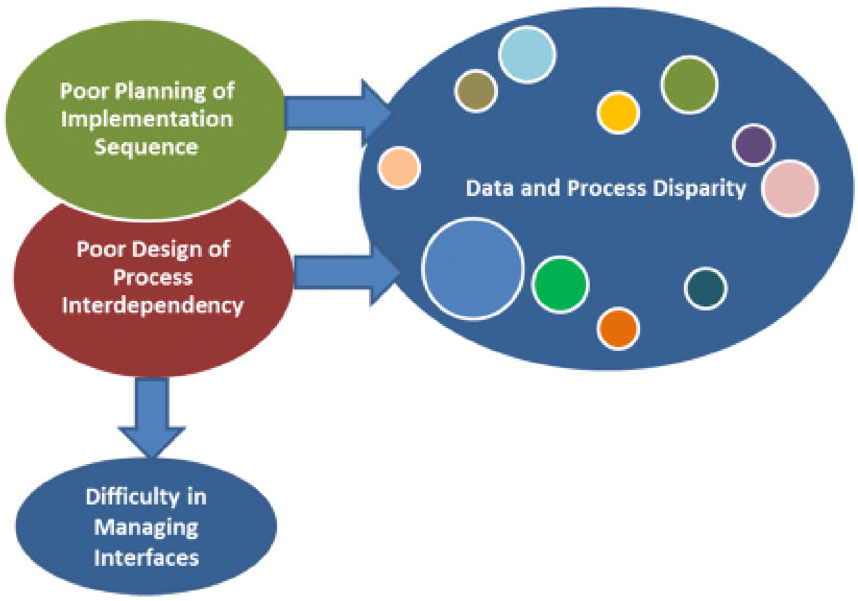



**Figure 4-8:** Poor Planning of Implementation Sequence and Poor Design of Process Interdependency

The differences in business process design across the modes, is a consequence of a lack of process standardisation. This is illustrated in Figure 4-9. Instances where processes are not standardised also generally lead to customisation in the ERP solution. Caution must be applied in customising the solution, as this can impede the internal integration of ERP modules (Momoh *et al.,* 2010; Thermistocleus *et al*., 2001; Shehab *et al*., 2004; McAdam *et al*., 2005). It is more beneficial to fit business processes to the ERP package rather than customise the package (Momoh *et al*., 2010; Sumner, 1999).

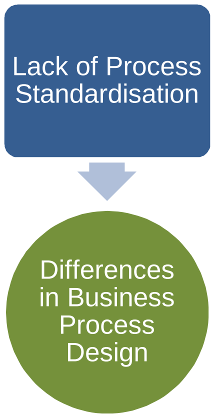



**Figure 4-9:** Lack of Process Standardisation

Furthermore, there was a lack of knowledge transfer on the project which caused the repetition of the same challenges encountered in different modes. An illustration of this is provided in Figure 4-10. The challenges reported in this case study were compared to the literature review results in chapter 2 of this thesis.

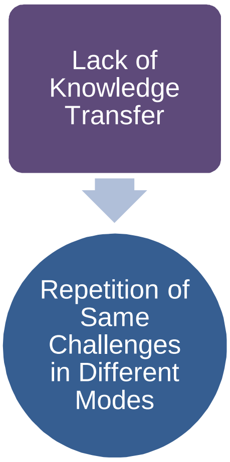



**Figure 4-10**: Lack of Knowledge Transfer

## 4.5 ERP Challenges and Complexities

Most of the challenges which have been reported from the findings of the case study conducted on Company O are presented as complexities in this section. The illustration is split into two categories; (1) complexities during implementation, and (2) complexities after implementation. Each category is a replication of that used for identifying the challenges. The former category is illustrated in Table 4-2, and the latter is presented in Table 4-3. The challenges are highlighted as complexity types in Table 4-2 and Table 4-3.

Five indicators have been used in Table 4-2 and Table 4-3 to identify which challenge is a complexity. These indicators are derived from the definition of complexity adopted in this research which is provided in Section 2.4. The definition highlights that a system is complex if its attributes make it difficult to use, understand, manage, implement, and/or have a potential to increase. Therefore, the indicators are specified as; (1) difficult to use, (2) difficult to understand, (3) difficult to manage, (4) difficult to implement, and (5) potential to increase.

**Table 4-2:** ERP Complexities during Implementation

| Complexity Type | Difficult to Use | Difficult to Understand | Difficult to Manage | Difficult to Implement | Potential to Increase |
|---|---|---|---|---|---|
| Substantial Customisation | • | | • | • | • |
| Process Duplication | | | • | | • |
| Poor Integration | • | | • | • | |
| Poor End-to-End Process Design | • | • | • | • | • |
| Problematic Implementation Sequence | • | | • | • | |
| Lack of Change Management | | • | | | |
| Internal Resource Unavailability | | | | • | |
| Minimal Understanding of ERP Solution | • | • | • | • | • |
| Poor Training | • | • | • | | |
| Poor Data Quality | • | • | • | • | • |
| Lack of Business Sponsorship | | | | • | |
| Resistance to Change | | | • | • | |
| Minimal Business Process Understanding | • | • | | • | |
| Poor Process Standardisation | • | • | • | • | |
| Poor Business Process Integration | • | | • | • | • |

**Difficult-to-Use Complexities**

The complexities which result in an ERP solution that is difficult to use are substantial customisation, poor integration, poor end-to-end process design, problematic implementation sequence, minimal understanding of ERP solution, poor training, poor data quality, minimal business process understanding, poor process standardisation, and poor business process integration.

**Difficult-to-Understand Complexities**

Out of all the complexity types in Table 4-2, poor end-to-end process design, lack of change management, minimal understanding of ERP solution, poor training, poor data quality, minimal business process understanding, and poor process standardisation constitute the complexities which arise in a difficulty in understanding the system.

**Difficult-to-Manage Complexities**

Most of the 15 complexities present an ERP system that is difficult to manage. These complexities are substantial customisation, process duplication, poor integration, poor end-to-end process design, problematic implementation sequence, minimal understanding of ERP solution, poor training, poor data quality, resistance to change, poor process standardisation, and poor business process integration.

**Difficult-to-Implement Complexities**

The ERP solution is presented as a system that is difficult to implement as a result of substantial customisation, poor integration, poor end-to-end process design, problematic implementation sequence, internal resource unavailability, minimal understanding of ERP solution, poor data quality, lack of business sponsorship, resistance to change, minimal business process understanding, poor process standardisation, and poor business process integration.

## Potential-to-Increase Complexities

Six complexities create a system which has the potential to increase in complexity. The complexities are substantial customisation, process duplication, poor end-to-end process design, minimal understanding of ERP solution, poor data quality, and poor business process integration.

The three major complexities that appear in all five categories are poor end-to-end process design, minimal understanding of ERP solution, and poor data quality. These complexities are on a very high scale. Figure 4-11 illustrates the contribution of each complexity category to the overall complexity of the ERP system.

There are 46 complexities derived from 15 complexity types across 5 complexity indicators, outlined in Table 4-2.

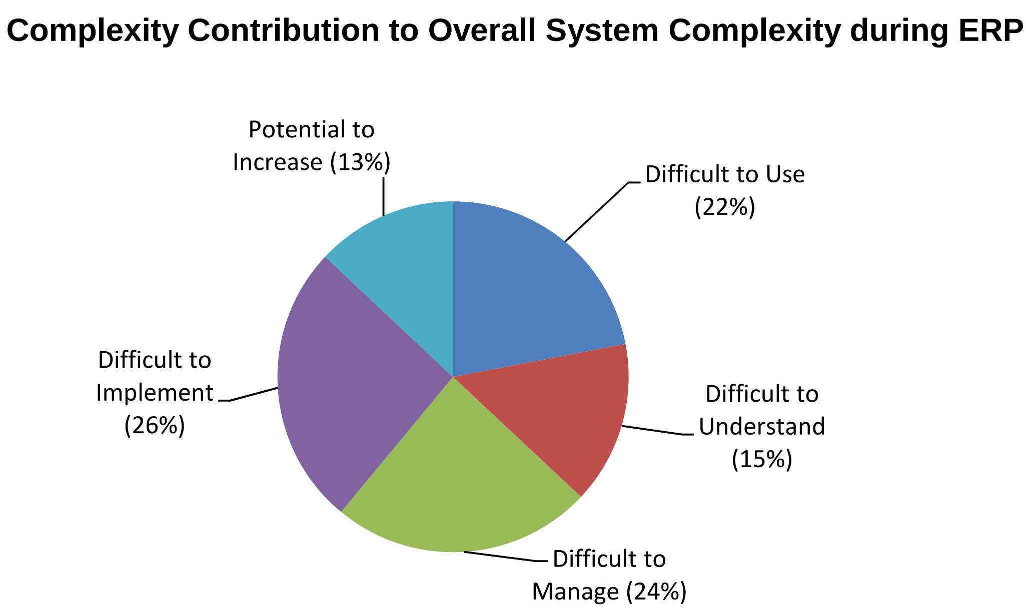



**Figure 4-11:** Contribution of System Complexity during Implementation

Figure 4-11 illustrates that 22%% of the complexities result in a difficulty to use the system. The complexities which create a difficulty for the project resources to understand the system contribute to 15% of the overall complexities. Another indicator of complexity is difficulty in managing the ERP solution, and 24% of complexities contribute to this problem. A fourth complexity indicator is a difficulty to implement the system and 26% of challenges fall under this category. Some complexities can result in increased complexity in the system and these contribute to 13%% of the overall complexity as indicated in Table 4-2.

**Table 4-3:** ERP Complexities after Implementation

| Complexity Type | Difficult to Use | Difficult to Understand | Difficult to Manage | Difficult to Implement | Potential to Increase |
|---|---|---|---|---|---|
| Poor Problem Resolution Response | | | • | | |
| Substantial Customisation Rework | • | • | • | • | • |
| Substantial Amount of System Upgrades | • | | | • | |
| Invisibility of Post-Go-Live Support Team | • | | | | |
| Uncontrolled Change Processes | • | • | • | • | • |
| Data Disparity | • | | • | • | • |
| Reduced Efficiency | | | • | | |
| Poor Understanding of Data/Report Extraction | • | • | • | • | |

Table 4-3 presents eight complexity types which are introduced into the system after implementation. Some of the complexities which surfaced after the implementation already exist in Table 4-2. Hence they are not re-presented in

Table 4-3. In this table, it is indicated that substantial customisation rework and uncontrolled change processes appear in all five categories. This implies that both complexity types will constitute a very high level of complexity in the system. The two complexities which contribute to four of the categories are data disparity, and poor understanding of data and report extraction. These complexities make the system difficult to use, difficult to manage, and difficult to implement. Unlike the latter complexity, data disparity does not necessarily make a system difficult to understand. And unlike data disparity, a poor understanding of data and report extraction does not necessarily create a potential for increased complexity in the system. A substantial amount of system upgrades makes the system difficult to use and implement. The lowest level complexities are poor problem resolution response and reduced efficiency which create a difficulty in managing the system, and invisibility of post-go-live support team which causes a difficulty in using the system. Figure 4-12 illustrates the contribution of the complexities which are introduced into the system after implementation. These are presented by category. Each category represents an indicator as specified in Table 4-3.

As illustrated in Figure 4-12, all the complexities which result in a system which is difficult to use and difficult to manage contribute to 26% of the overall complexity. In terms of the complexities which create a difficulty in implementing the system, these contribute to 22% of the overall complexity. Finally, complexities with a potential to increase in the system and also make the system difficult to understand constitute 13% of the complexities in the system.

It is apparent from both Figure 4-11 and Figure 4-12 that the complexities which score the highest in the ERP solution make the system difficult to use, manage and implement. This is a strong indication that the Company O ERP solution was very complex. It is for this reason that the implementation cost was so high.

**Complexity Contribution to Overall System Complexity after ERP Implementation**

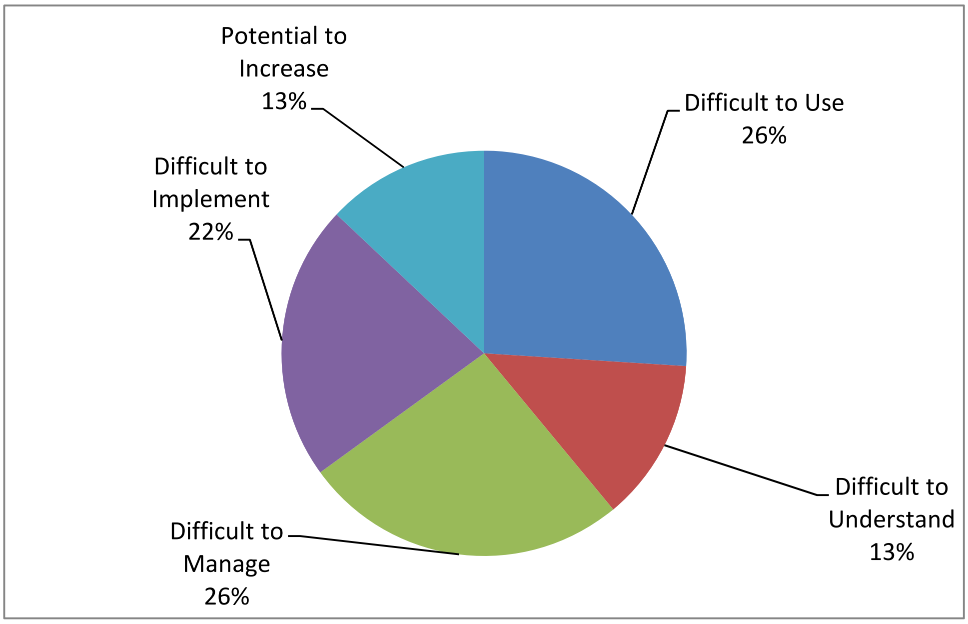



**Figure 4-12:** Contribution of System Complexity after Implementation

## 4.6 Cost Estimating Practice

Cost estimating of the ERP project implementation in Company O was standard practice across the ERP industry. The primary cost drivers which are required in the costing process are the number of resources, daily rate for each resource and resource effort for the activity to which they are allocated. The product of these cost drivers generates an activity cost. The cost of backfilling full-time resources was also added to this cost. A total of all the costs per activity results in an implementation cost. The duration for each activity is used to calculate the effort for each resource, and it is derived from the values for the relevant cost drivers listed in Table 2-8. A single-point estimate was used to calculate the duration for each activity. The software license cost was also estimated through the database cost, the number of users and the cost of number of modules. However ERP software licensing is outside the scope of this research.

The complexities in the project increased, which in turn increased the resources and implementation cost. The cost increase was uncontrollable, and the organisation was not aware of the complexities which generated this increase. The cost overrun was £2 million. As they deployed more resources onto the project, they lost sight of the key challenges and complexities of the implementation. If the complexities had been anticipated, and if their cost was estimated through the project resources, Company O would not have overrun on cost in the way they did. They would have been in a position to control the potential complexities through their resources, thereby reducing the implementation cost.

## 4.7 Comparison of Case Study Findings with Literature Review

At the conclusion of the case study with Company O, its findings were compared with the literature review findings on complexity factors and cost estimating techniques. Based on Table 2-4 and Table 4-2, the complexities which both studies share in common are substantial customisation, poor integration, lack of change management, internal resource unavailability, poor training, poor data quality, and minimal business process understanding.

In terms of cost estimating, Organisation O used a single-point estimate to specify the duration of each activity. Hence they did not cater for uncertainty using three-point estimating which is discussed in Section 2.9.1. The cost drivers which both studies share in common based on Table 2-8 are number of business processes, travel cost (incorporated in the resource daily rate for Company O), size of company, number of users, number of legacy applications, number of sites, backfilling cost, labour cost, data cleansing, data conversion, testing, reports generation, interfaces, level of customisation, number of software licenses, database cost, and number of modules.

## 4.8 Summary

This chapter discussed the current practice in Company O, as a case study. The study was conducted with an analysis of the situation of the ERP implementation, and a series of semi-structured interviews. The rationale behind implementing an ERP solution was highlighted. Subsequently, the challenges which were encountered during and after the implementation were presented. Additionally, the phase-specific issues which were caused as a consequence of the implementation were discussed in detail. To finalise the findings, the challenges were linked to ERP complexities which were illustrated. The complexities were categorised as; (1) difficult to use, (2) difficult to understand, (3) difficult to manage, (4) difficult to implement, and (5) potential to increase complexity. Identifying these complexities and challenges fulfilled one of the objectives of this research.

The case study was conducted across three modes; Mode 1, Mode 2 and Mode 3. There were eleven participants in the case study; the Project Sponsor, Head of Business Planning, Head of SAP Competence Centre, Head of Performance and Systems, Director of Internal Audit, Director of Group Procurement, Director of Finance, Business Operations Manager, Group Director of HR, Procurement Manager, and Customer Services Manager.

The next chapter discusses the development of the ERP resource complexity costing framework.

# 5 OVERALL ERP COMPLEXITY FRAMEWORK DEVELOPMENT

## 5.1 Introduction

According to the literature review conducted in this research, it is evident that the assessment and costing of complexity in the ERP realm has not gained as much attention as in software development. A number of metrics have been defined for measuring the complexity of software development. In the process of this development, ERP system implementation cost continues to grow as a consequence of its encountered complexities. New complexities have emerged, and the old complexities still exist. As complexities emerge, they increase in number exponentially and are difficult to control and measure. Consequently, ERP implementation costs are poorly estimated and overrun because of the absence of complexity costing. Therefore, identifying each complexity, evaluating it and adding it to an ERP implementation resource cost will contribute significantly towards providing a realistic project cost for a potential ERP adopter. This is an area in research that must be addressed.

This chapter presents an overall framework of the research covered in this thesis. The two phases in the framework are briefly illustrated, which are ERP Complexity Assessment, and Cost Estimation of Resource Complexity. The framework is embedded in a tool known as Complexity of Resource and Assessment Costing Tool (C-REACT). Additionally, in this chapter, the development of the complexity factors and cost drivers which are produced from literature review, interactions with industry through surveys and interviews, refinement and conceptual validation, and the researcher's work experience, are presented. These complexity factors and cost drivers are used as the basis for complexity assessment. The organisations that participated in producing the developed complexity factors and cost drivers for application in this research are from the industries of oil and gas, aerospace and defence, electronics manufacturing, ERP consulting, banking, risk analysis consulting, fertiliser and petro-chemicals production, and entertainment. A total of thirteen organisations were involved in the development of the ERP complexities adopted in this research. The essence of engaging this number of organisations was to attain richness of data through a variety of organisations from various industries. Secondly, the data gathered would enable a generic taxonomy to be identified across all the organisations for application in C-REACT. Freelance information technology (IT) complexity experts and ERP experts were also involved in this process. Figure 5-1 depicts the outline of this chapter. In conjunction with the literature review of this thesis, this chapter fulfils the following research objectives:

- Investigate the complexity factors inherent in ERP implementations which will define a complexity taxonomy that enables the identification of complexities for resource complexity assessment and cost estimation
- Analyse the cost drivers which enable the costing of complexity in ERP implementations in order to support the cost estimation of resource complexity

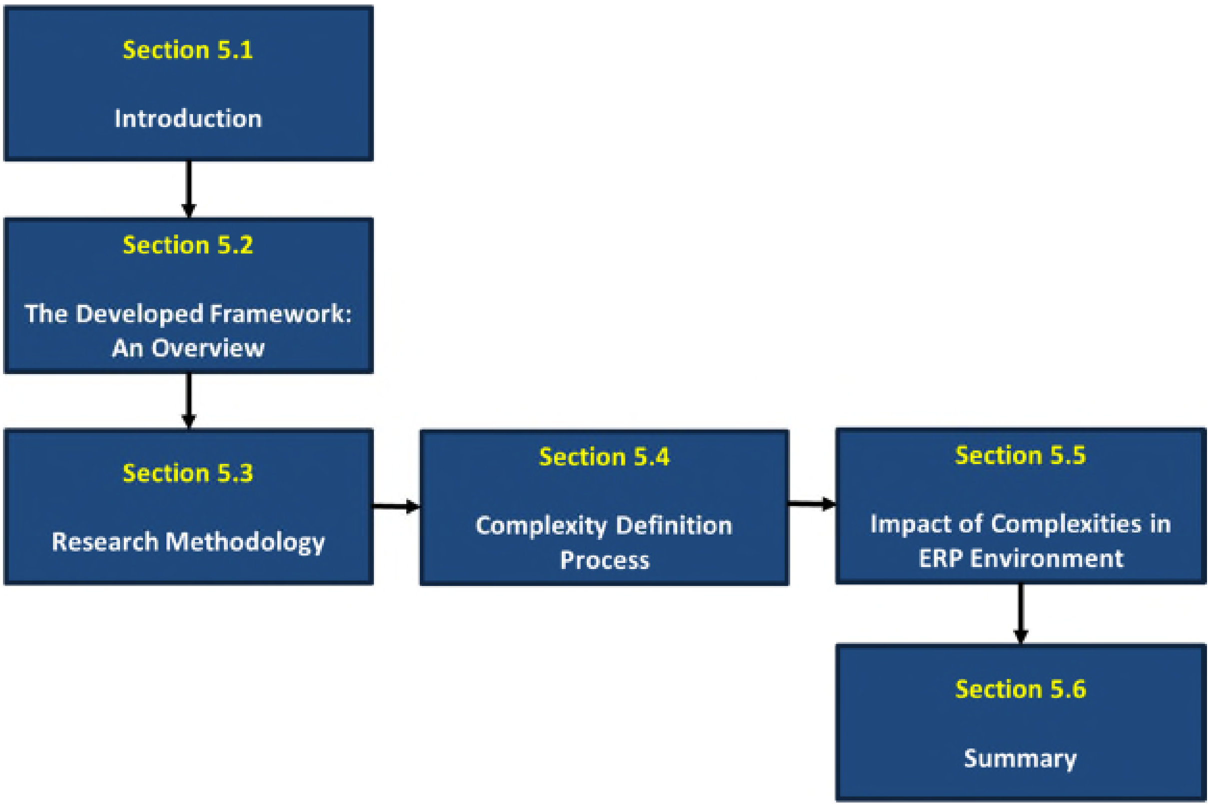



**Figure 5-1:** Outline of Chapter 5

## 5.2 The Developed Framework: An Overview

This research develops a framework which is embedded in a tool to identify, assess and cost ERP resource complexity through simulation. The framework is known as Complexity of Resource and Assessment Costing Tool (C-REACT). The overall framework is presented in Figure 5-2 and comprises of two phases.

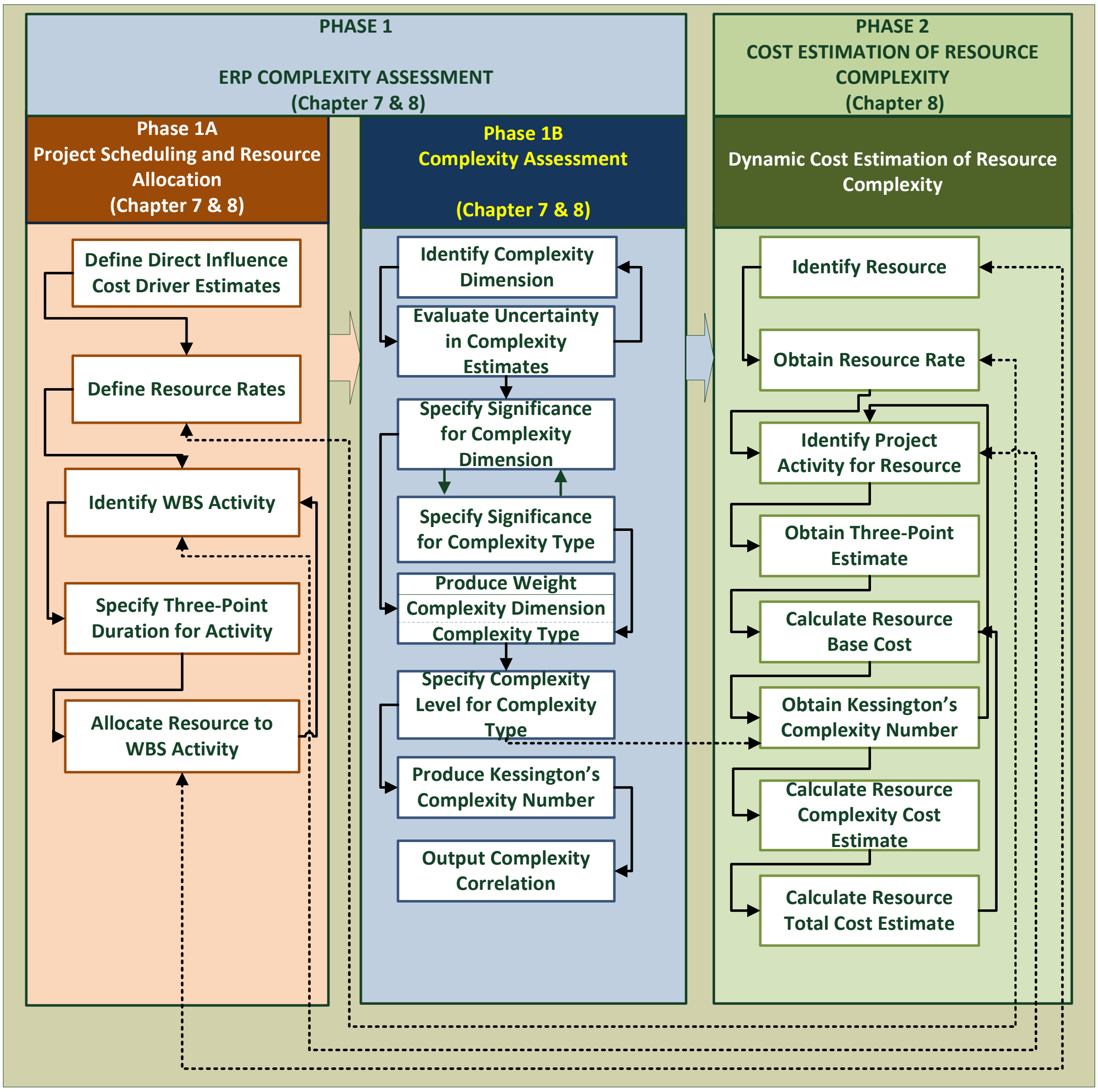



**Figure 5-2:** Overall Framework for Costing ERP Resource Complexity

## Phase 1

This phase constitutes two parts, phase 1A and phase 1B. Phase 1A defines the work breakdown structure for scheduling the project activities within which the resources experience complexities. This is a compulsory process in the complexity assessment phase. The resources required for each activity are also allocated to their relevant activity. The project duration is scheduled using three-point estimating to cater for the uncertainties in the duration forecasting.

In this process, the respective members of the project team are allocated to their various project activities for costing. The WBS produces the platform for calculating the resource base cost which feeds into the resource complexity cost. The development of the work breakdown structure elements is discussed in Chapter 6.

Phase 1B enables the identification of the complexities experienced in ERP implementations by project resources. This is a pivotal process in the complexity assessment phase. A taxonomy of complexities is embedded in the framework to enable the understanding and identification of the relevant complexities which would be applied in cost estimating. A detailed description of the complexity identification process is provided in Chapter 7. Subsequently, the complexity assessment process is executed. The framework enables the user to assess each complexity by scoring its level of significance and by specifying a level of complexity from five levels on a scale of one to five using the likert scale. The five levels represent 1 for very low, 2 for low, 3 for medium, 4 for high, and 5 for very high. Each level is a distinction of the degree of complexity which exists for the relevant complexity type. Level 1 indicates the lowest amount of complexity and level 5 reflects the highest amount of complexity. This is an indication that the degree of complexity is not uniform, as it can increase or decrease. The complexity level is normalised and multiplied by a weight which is derived from its ranking of significance through a technique known as analytical hierarchy processing (AHP), to produce a complexity score known as Kessington's complexity number (KCN). AHP is a multi-criteria decision method which enables a prioritisation of preference decisions. KCN determines the amount of complexity in each activity, which is experienced by the resources in these activities. KCN is used as an input in the calculation of the resource complexity cost.

**Phase 2**

Phase 2 of C-REACT simulates the cost estimation process for the complexity experienced by each resource through agent based modelling. The three-point estimates defined for the duration of each project activity, are simulated as triangular distributions. A base cost without assessed complexity is produced for each resource. The resource complexity cost estimate is generated by multiplying the resource base cost by its KCN using Monte Carlo simulation.

## 5.3 Research Methodology

The complexity of ERP implementation projects is a heavily discussed subject both in research and industry. However, complexity has not yet been fully defined. Its meaning and causes are still obscure amongst researchers and practitioners. Therefore, the researcher adopted a methodology that will enable the definition of a comprehensive taxonomy of complexities and associated cost drivers for assessment, and the project activities and resources for which the complexity cost will be estimated. Figure 5-3 presents a research methodology that covers the research methodology for the overall framework development.

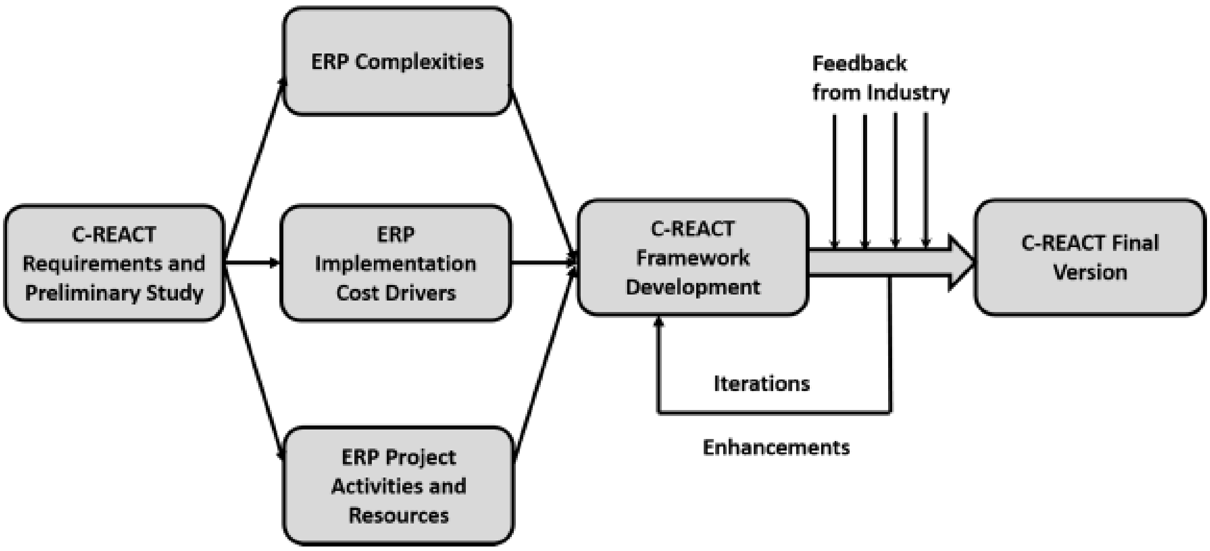



**Figure 5-3:** Research Methodology for Overall Framework Development

The development of the complexities and related elements was an iterative process. Defining each complexity related element commenced with a literature review to discern the meaning of complexity, and its associated elements. Subsequently, the researcher presented the outcome of the literature review to industry and individual ERP experts for their opinions, through interviews and online surveys. As the researcher revised the results of the interviews and online surveys, she presented the complexities, cost drivers, project activities and resources to industrial collaborators who participated in the conceptual validation of the elements. These participants refined the relevant elements until a final version of complexities, cost drivers, project activities and resources were produced for implementation in C-REACT. The development of the work breakdown structure for project activities and resources is presented in Chapter 6. It fulfils the research objective to design a work breakdown structure for ERP implementation activities and resources for which complexity cost will be estimated.

### 5.3.1 ERP Complexities

A complexity taxonomy was developed for C-REACT to enable the identification, assessment and costing of ERP complexities for each project resource. A research methodology was adopted in the development of the complexity taxonomy. An overview of the steps taken to define the complexity taxonomy is presented in Figure 5-4.

#### 5.3.1.1 Phase 1 – Familiarisation of ERP Complexities

The first step in defining an ERP complexity taxonomy which would be embedded in the framework, entailed a combination of a comprehensive literature review, semi-structured interviews with six organisations, one ERP expert, surveys with twenty-one participants, and the researcher's SAP implementation experience.

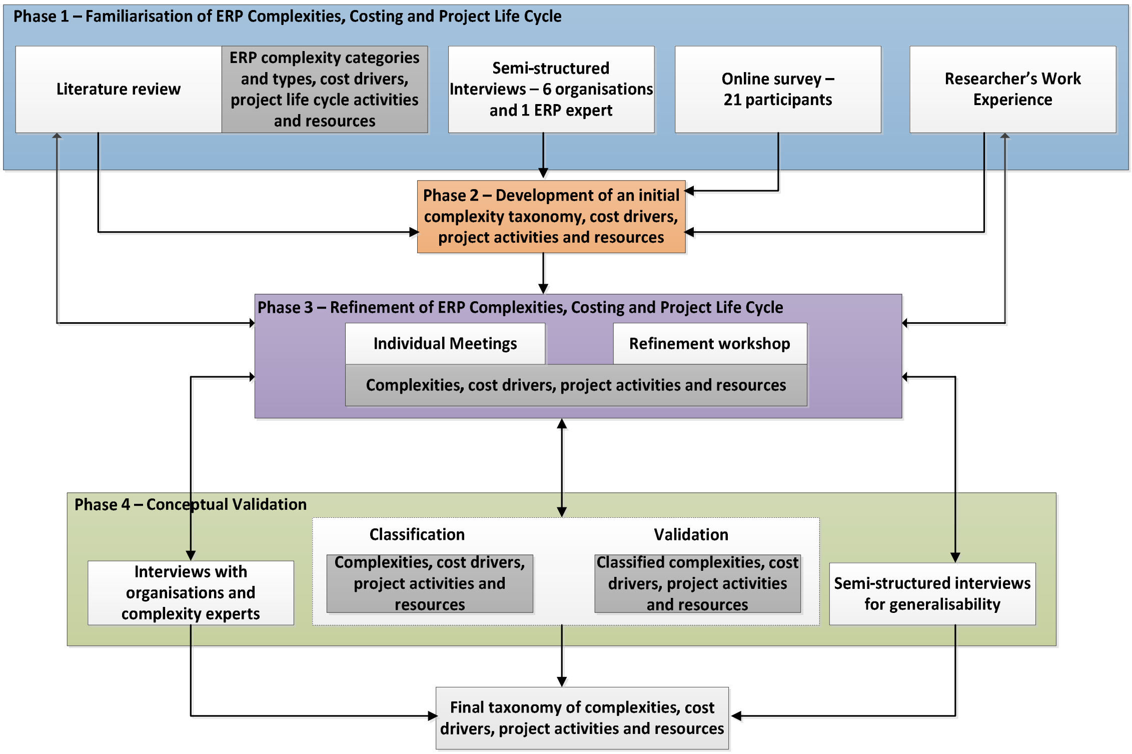



**Figure 5-4:** Research Methodology to Derive Initial List of Complexities

### Literature Review Findings

An extensive literature review was conducted in combination with the researcher's ERP implementation experience, to obtain a detailed understanding of the complexities inherent in ERP implementations. An indepth study was also conducted on the metrics for complexity measurement and costing. The literature review constituted published material on software and ERP complexity factors, complexity categories, complexity metrics, and project cost estimation. The key findings from the literature review for complexity classifications and characteristics are:

- a complex system may be in any or all of the states;
    - ➢ difficult to understand
    - ➢ difficult to use

- difficult to manage
- difficult to implement
- has a potential to increase.

- complexity is also characterised by multiplicity, diversity and interrelatedness
- in relation to enterprise resource planning implementations, the categories for measuring complexity as discussed in Chapter 2 are;
  - variety which reflects the number of elements and their relationships in a given situation
  - variability which relates to the dynamics over time of its elements and the interrelationships between them
  - integration which characterises the planned changes to be realised through the implementation program in terms of integration of IT systems and across business processes
- in the context of enterprise resource planning implementations, complexity is most commonly classified as;
  - structural which is associated with the topological relationships of a system's components
  - functional which is an inherited complexity from the modelled business domain which cannot be measured quantitatively
  - cognitive which refers to the effort necessary for an implementation specialist to understand the software product on which they are working

The study on complexity revealed that there was not a standard definition for complexity. Therefore, the researcher adopted a complexity definition for this research. Complexity is defined as the attribute of a system that makes that system difficult to use, understand, manage, implement, and/or with a potential to increase. In order to provide a more detailed understanding of the characteristics of complexity, the researcher selected six complexity categories from the literature review as illustrated in Figure 5-5. The developed complexities would be classified into these categories. The complexity categories are structural complexity, functional complexity, cognitive complexity, variety complexity, variability complexity, and integration complexity, which have all been described above. In the literature review, other categories were defined such as computational complexity, behavioural complexity, organic complexity, logical complexity and textual complexity. However, the focus of this research is on the kinds of complexity experienced and inherent in the implementation of the software product, enterprise resource planning. Therefore, the research is more concerned with the functional and structural aspects of ERP, and their integration.

As part of the key literature review findings, forty-three complexity types were identified. These complexity types were further mapped to their relevant complexity categories based on the definitions provided for the latter. These complexity types were mapped to the structural, functional, cognitive, variety, variability and integration complexity dimensions as illustrated in Chapter 2.

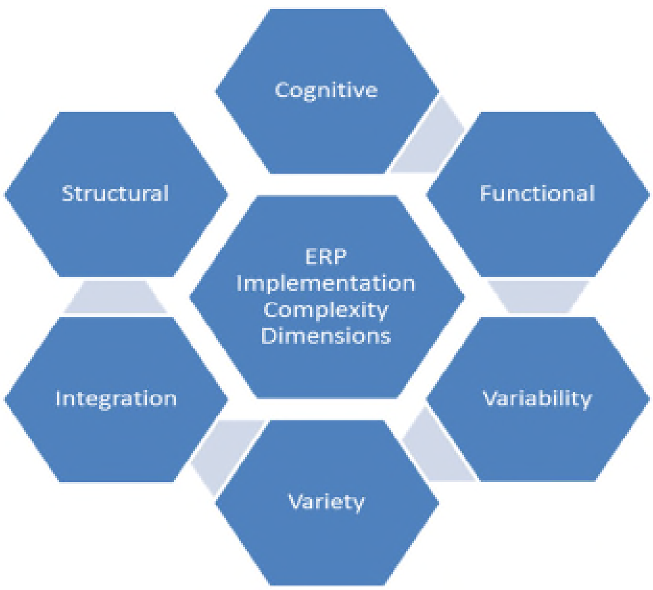



**Figure 5-5: ERP Complexity Categories from Initial Literature Review**

The researcher added the following complexity types to those defined in Chapter 2, based on her work experience as an ERP consultant:

- **Resistance to change** – in the event that the organisational staff resist the new ERP solution, this will create a delay in implementation and might impede its success.
- **Differences in business units** – some organisations are composed of a number of legal entities where each entity operates on its own as a separate organisation. These entities are sometimes referred to as business units. An increase in business units can delay an ERP implementation due to its diversity and multiplicity which would arise in complexity.
- **Appropriateness of selected system** – if the selected ERP solution is inappropriate for the adopter, this will most likely lead to a failed implementation resulting from a myriad of complexities.
- **Impact of backfilling project resources** – in order for an organisation to deploy its best human resources to an ERP implementation project on a full-time basis, it is imperative that these resources are replaced in the business so that normal business activity will continue. In the event that these resources are not replaced, the organisational operations will be disrupted which will lead to loss of income. However, should these resources be placed on the project on a part-time basis because of a difficulty in backfilling, the project will not obtain the constancy of business process knowledge infusion required for a successful implementation.

### Interviews and Online Surveys

The next step from literature review was to conduct semi-structured interviews and online surveys. The findings from the literature review, the outcomes of the current industrial practice, and the researcher's work experience were used to develop the initial complexity taxonomy. These results were presented in the semi-structured interviews with six organisations and one ERP expert, and online surveys with twenty-one participants. The organisations involved in the semi-structured interviews reflected diversity and globalisation, as they were from the United Kingdom, Switzerland, Brazil and Nigeria. Each interview lasted for an hour and a half. All the participants involved in the interviews and surveys are outlined in Table 5-1. The essence of the interviews and online surveys was to establish the complexities in an ERP implementation and whole life cycle altogether.

Three different questionnaires were created for the interviews and surveys:

- The first questionnaire was split into two; parts A (see Appendix A.1) and B. Part A was designed to obtain data on ERP complexity factors, cost drivers and whole life cycle stages. Part B was tailored towards gathering data on the actual cost of ERP whole life cycle stages, and effort and resources required for each of the whole life cycle stages and activities. All the data gathered from the participants of both questionnaires would be used to develop the framework.

- The second questionnaire was a scaled down version of Part A. This was used in the online survey. The questions were reduced in order not to deter the online participants due to the intensity and volume of the questions.

The key interview questions for complexity factors asked during the interviews are presented in Table 5-2. The information collated from the key questions is very critical and would enable the researcher to define the relevant data on complexity for implementation in C-REACT.

**Table 5-1:** Participants of Semi-Structured Interviews

| Expert | Organisation | Position in Organisation | Position in ERP Project | Years of Experience |
|---|---|---|---|---|
| Expert 1 | Company A | Project Manager | Project Manager | 16 |
| Expert 2 | Company A | Project Coordinator | Project Coordinator | 7 |
| Expert 3 | Company D | Infrastructure Supervisor | Infrastructure/Support Specialist | 15 |
| Expert 4 | Company E | IT Manager for Business Change | Project Manager | 22 |
| Expert 5 | Company E | ERP Functional Consultant | ERP Functional Consultant | 13 |
| Expert 6 | Company F | Head ERP Competency Centre | Project Manager | 13 |
| Expert 7 | Company G | Chief Executive Officer/Implementation Partner | Implementation Partner Project Manager | 33 |
| Expert 8 | Company H | Head of Operations | Chief Information Officer/Head ERP Project Infrastructure | 18 |
| Expert 9 | Company H | Chief Operations Officer | Project Manager | 15 |
| Expert 10 | Freelance | ERP Functional Consultant | ERP Functional Consultant | 16 |

**Table 5-2:** Key Interview Questions on Complexity Factors and Cost Drivers

| Question Area | Key Questions |
|---|---|
| **Complexity and Costing of ERP Whole Life Cycle** | Was your ERP project completed according to time and budget? |
| | What are the factors that make ERP whole life cycle complex? |
| | Specify the relationship between each complexity factor and other complexity factors |
| | What are the complexity factors that are presented in each stage of the ERP whole life cycle? |
| | What are the cost drivers that contribute to an ERP whole life cycle costing? |

#### 5.3.1.2 Phase 2 – Development of an ERP Complexity Taxonomy

The taxonomy of complexities was produced from the outcomes of the interviews and surveys. This complexity taxonomy is refined in a later phase by the conceptual validation participants.

Part A of the first questionnaire, as well as the online questionnaire presented a semi-closed question on complexity factors to the participants. Thirty-five complexity options were provided to the participants, from which the online survey participants were required to select the top ten, and the interviewees were advised to select the top twenty. The essence of requesting fewer options from the online participants was to encourage them to complete the questionnaire by not overwhelming them with too many questions. As the survey was based online, the researcher had no control over who completed or did not complete the questionnaire. However, there was more control over the interviews, hence, it was easier to present the interviewees with more options from which to select.

The end of the question on ERP complexities provided an 'Other' option for the participants to specify complexity factors which had not been incorporated in the initial set of options.

Twenty-one participants responded to the question on complexity factors, and a total of eight interviewees selected some of the options on this question. The total number of interviewees and participants was twenty-nine.

Out of all the options that were selected by the online participants and interviewees, the top fifteen were ranked for use in the C-REACT Framework. Table 5-3 illustrates the rankings of the top fifteen complexities which were selected by the participants. The researcher focussed on the top fifteen complexities in order to enable easy management of the complexities in the process of their identification, assessment and costing in the ERP resource complexity costing framework.

**Table 5-3**: Complexity Factors from Interviews and Survey

| Complexity Factor | Number of Interview Participants | Online Survey Participants | Total Number of Participants | Percentage | Ranking |
|---|---|---|---|---|---|
| Business Processes | 6 | 23 | 29 | 100% | 9 |
| Level of Customisation | 6 | 19 | 25 | 86% | 8 |
| Data Cleansing and Conversion | 6 | 19 | 25 | 86% | 8 |
| Availability of Experienced Resources | 7 | 17 | 24 | 83% | 7 |
| Number of Systems to be Replaced | 5 | 15 | 20 | 69% | 6 |
| Readiness | 4 | 15 | 19 | 66% | 5 |
| System Configuration | 4 | 14 | 18 | 62% | 4 |
| Process Relationships | 5 | 13 | 18 | 62% | 4 |
| Extent of Goal and Scope Change | 4 | 14 | 18 | 62% | 4 |
| Reliance on Third Party Labour | 6 | 10 | 16 | 55% | 3 |
| Level of Internal Resource Participation | 5 | 11 | 16 | 55% | 3 |
| Number of Modules | 4 | 12 | 16 | 55% | 3 |
| Functions | 4 | 11 | 15 | 51% | 2 |
| Structural Integration | 4 | 11 | 15 | 51% | 2 |
| Number of Users | 5 | 9 | 14 | 48% | 1 |

**Number of Participants = 29**

Although several complexity factors held the same ranking, the ranking numbers used were 1 to 15; 1 being the lowest and 15 being the highest. This scale was applied in order to reflect the number of complexity factors. However the highest rank achieved in order to attain fifteen complexity factors, was 9. This is as a consequence of certain complexity factors holding the same rank. The percentage of participants that selected each complexity factor is presented in Figure 5-6.

The selected fifteen complexity factors were classified as dimensions by the researcher. Each complexity dimension was further split into complexity types prior to presentation for refinement.

Once these complexities were established from the interviews, surveys, literature review and the researcher's experience, they were presented in a refinement workshop for further verification.

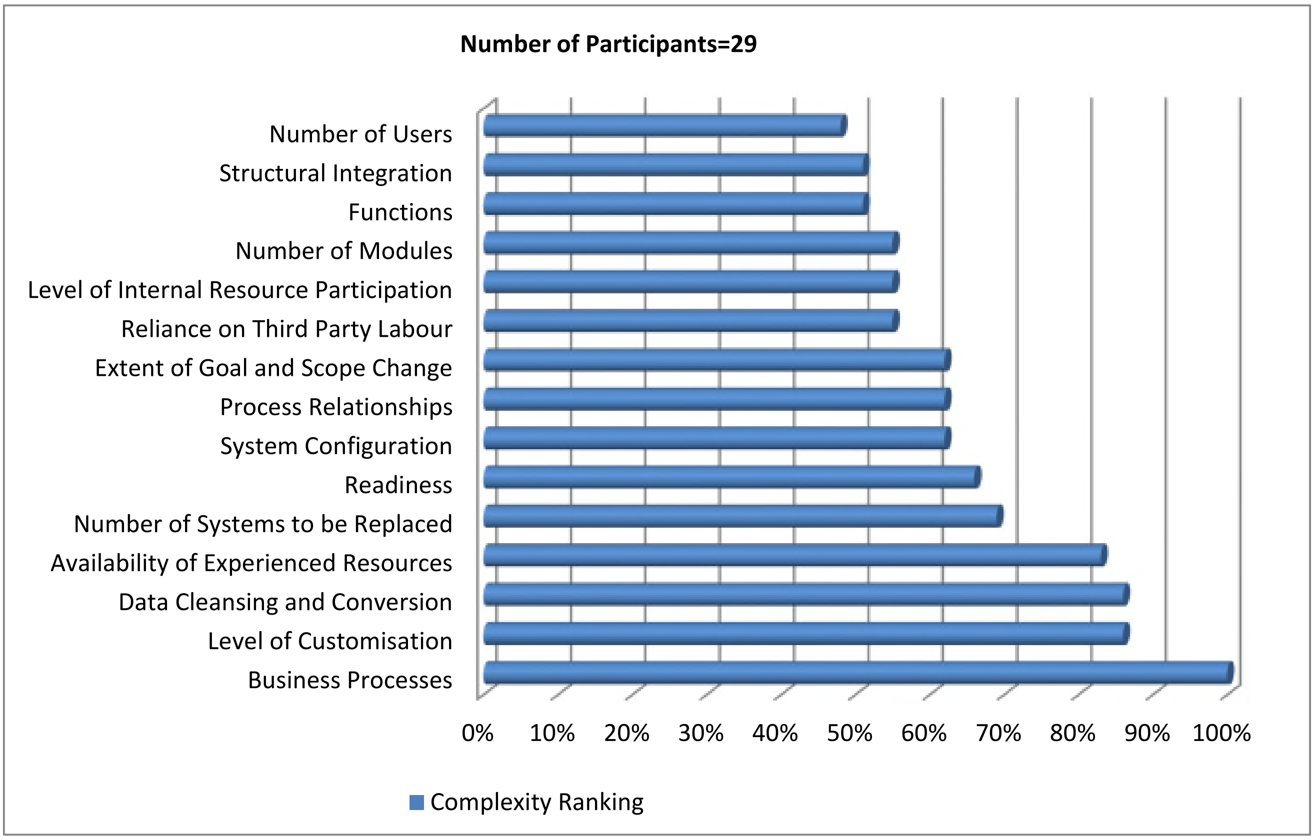



**Figure 5-6:** Complexity Factor Proportion in Survey

#### 5.3.1.3 Phase 3 – Refinement of ERP Complexity Taxonomy

Subsequent to developing a complexity taxonomy, was the refinement meetings and workshops. The meetings and workshops involved participants from two consultancies, and an aerospace and defence organisation, as outlined in Table 5-4.

**Table 5-4:** Participants of Refinement Workshop and Meetings

| Expert | Organisation | Position in Organisation | Position in ERP Project | Years of Experience |
|---|---|---|---|---|
| Expert 11 | Company J | Project Manager | Project Manager | 20 |
| Expert 14 | Company J | ERP Manager | Project Manager | 23 |
| Expert 15 | Company C | Associate Director | Project Manager | 16 |
| Expert 17 | Company B | Programme Manager | Programme Manager | 16 |

The complexity taxonomy was an input to the refinement process which was conducted through two individual meetings for each participating organisation, and a WebEx workshop with all the participants. The purpose of this process was to present the outputs from the semi-structured interviews and online survey to industry for their verification. The organisations involved in this phase were also involved in the conceptual and tool validation of C-REACT.

The researcher advised the participants of the refinement meetings and workshops that a decision making technique known as analytical hierarchy processing (AHP) will be used in the complexity costing tool to compare and assess the complexities (see Chapter 7). One of the criteria for using AHP is to present a maximum of seven items for comparison, as posited by Bahurmoz (2006). Hence the researcher suggested that the complexity dimensions be further reduced in order to meet the AHP requirements.

Consequently, the participants recommended eleven complexity dimensions, as illustrated in the mindmap in Figure 5-7, which was produced by Company B. All the boxes on the mindmap represent complexity dimensions. The boxes in red are new complexity dimensions (two) with new complexity types. The branches in red which are attached to complexity dimensions in blue boxes are new complexity types (thirty-one). In addition to these changes, the complexity dimension called extent of goal and scope change was renamed to project control. Furthermore, a new complexity dimension called external factors was added to the initial taxonomy of complexities. Its complexity types are market demand for ERP implementation, inflation rates, and exchange rates. This new dimension enables the C-REACT framework to cost the impact of external factors on the ERP implementation. As this has not been mentioned in literature, it is an indication that this complexity type is often neglected in the estimation of ERP implementation

In terms of inflation and exchange rates which constitute external factors, an unbalanced fluctuation may lead to an inconsistent implementation as a result of the implementing organisation's attempt to stop and start their implementation in an attempt to maintain affordability.

#### 5.3.1.4 Phase 4 – Conceptual Validation of Complexities

The fourth phase of the methodology for complexity development was the conceptual validation of the complexities, cost drivers, project activities and project resources. However, this section only addresses the validation of complexities. This activity involved sixteen participants from six organisations, one complexity expert from industry and a freelance complexity expert who had developed an IT complexity model for the banking industry in Germany. The roles and length of experience for each participant are provided in Table 5-5.

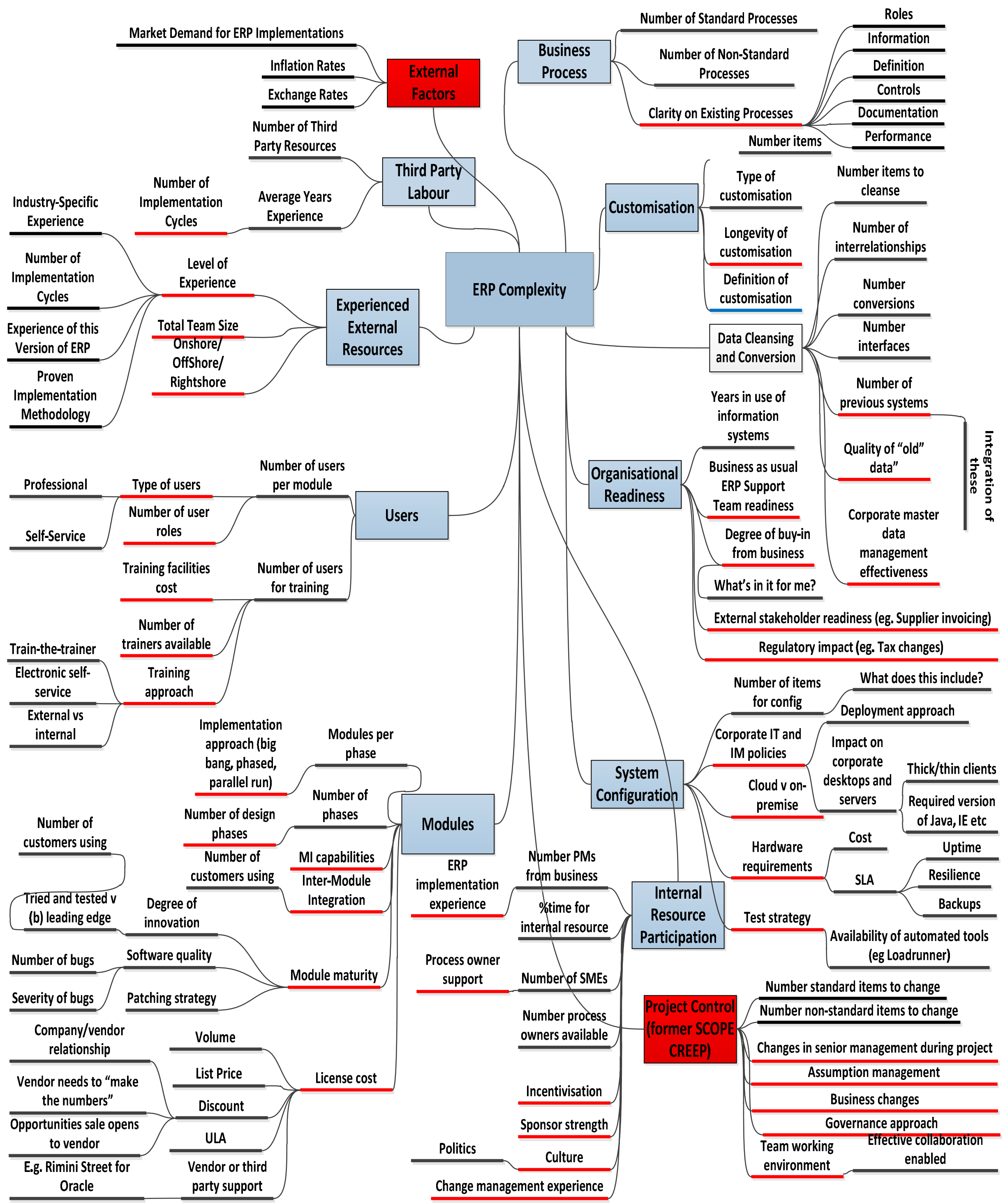



**Figure 5-7:** Complexity Mindmap from Refinement Process

**Table 5-5:** Participants in Conceptual Validation

| Expert | Organisation | Position in Organisation | Position in ERP Project | Years of Experience |
|---|---|---|---|---|
| Expert 11 | Company J | Project Manager | Project Manager | 20 |
| Expert 12 | Company J | ERP Functional Consultant | ERP Functional Consultant | 12 |
| Expert 13 | Company J | Authorisations Specialist | Authorisations Specialist | 7 |
| Expert 14 | Company J | ERP Manager | Project Manager | 23 |
| Expert 15 | Company C | Associate Director | Project Manager | 16 |
| Expert 16 | Company C | ERP Cost Estimator | N/A | 9 |
| Expert 17 | Company B | Programme Manager | Programme Manager | 20 |
| Expert 18 | Company I | Partner | Project Manager | 33 |
| Expert 19 | Company I | Functional ERP Consultant | Functional ERP Consultant | 10 |
| Expert 20 | Company I | Technical ERP Consultant | Technical ERP Consultant | 6 |
| Expert 21 | Company I | Functional ERP Consultant | Functional ERP Consultant | 5 |
| Expert 22 | Company K | SAP/ERP Technical Consultant | SAP/ERP Technical Consultant | 8 |
| Expert 23 | Company K | Supply Chain Projects Leader | Process Owner | 14 |
| Expert 24 | Company K | Technical Head Programme Management | Technical Head Programme Management | 28 |
| Expert 25 | Company K | Project Manager of IT for Supply Chain | Project Manager | 26 |
| Expert 29 | Company L | ERP Manager | Programme Manager | 16 |
| Expert 26 | Company M | Complexity Expert | N/A | 23 |
| Expert 27 | Freelance | Principal Enterprise Architect | IT Complexity Expert | 30 |

The collaborating organisations that participated in the conceptual validation were from the industries of aerospace and defence, ERP consulting, and risk analysis consulting. This mixture enabled a rich and comprehensive view of ERP complexity. Both consultancies and adopters usually have different opinions because they have different experiences which are required and pivotal in identifying, assessing and costing complexity. None of these organisations participated in the initial interviews and surveys. However, three of the organisations engaged in the refinement of the complexity taxonomy.

The conceptual validation commenced with individual meetings with the participants of each organisation. Thereafter, a WebEx workshop was conducted with all the participating organisations present. In total, five workshops were held, each lasting two hours. In between workshops, the researcher conducted individual meetings with each organisation in order to obtain their full attention and unbiased views. There was a total of fifteen meetings held with Company J, most of which were conducted with the senior ERP consultant who was the focal point for interaction with Company J.

Each of the meetings lasted two hours. Eleven meetings were held with Company C, each lasting two hours. Company B attended fifteen individual meetings, each lasting between one and two hours. Five individual meetings were held with Company I, each lasting one hour. Company K attended four individual meetings, with each one lasting two hours, and Company L attended two meetings, each one lasting two hours. Each of these meetings also incorporated the conceptual validation of project activities and resources, which is discussed in Chapter 6.

The complexity expert from Company M attended three individual meetings lasting a total of six hours, and Expert 27 attended one individual meeting lasting two hours. A joint workshop was organised by the researcher with both complexity experts, which lasted for two hours.

**Final Taxonomy of Complexities**

The inputs to the conceptual validation process for complexities are the complexity mindmap in Figure 5-7, the bar chart of complexity dimensions in Figure 5-6, and a presentation of complexity dimensions and types defined by Kumar (2011) in Chapter 2. The method for validating the ERP complexities entailed three steps; study questionnaire, assess and amend complexities, and refinement process.

The researcher produced one questionnaire which was used to score the complexities in the validation process. The participants also scored the mapping of complexities to project activities. Some of the questions presented to the participants are:

a) The bar chart below illustrates the top 15 complexity dimensions which were selected by the participants of the survey conducted as part of this research. Please provide your view on the number of complexity dimensions (out of the 15 illustrated) which should be catered for by the model.
b) Evaluate the complexity dimensions presented on a scale of 1 to 5 (1 being strongly irrelevant and 5 being strongly relevant)
c) Evaluate the complexity types on a scale of 1 to 5 (1 being strongly irrelevant and 5 being strongly relevant)

After scoring the complexities, the researcher collated all the suggestions made by the participants and highlighted them in a refinement questionnaire which was presented to the participants for scoring. This refinement questionnaire is presented in Appendix A.3. Some of the questions provided for the participants' feedback are outlined in Table 5-6.

**Validation Feedback**

The participants of the conceptual validation were satisfied with the complexities and associated cost drivers which were produced as inputs to the validation process. The complexity dimensions were split amongst four organisations for validation and further review by the whole group of participants. One of the critical comments which was made by the participants is that the final taxonomy of complexity dimensions, complexity types and associated cost drivers is a structured way to enable the identification and costing of complexity.

**Table 5-6:** Sample Subjects from Refinement Questionnaire

| Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly Agree |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| **Subject ID** | **Subject Area** | **Subject** | | |
| CDT.B1.1 | Proposal for Change Management as Complexity | It is proposed that Change Management be treated as a complexity instead of incorporating it in the ERP project methodology. Adding it to the project methodology will require associated activities. Besides, change management is run as a separate project from the ERP implementation project by some organisations. Although both projects are run concurrently. | | |
| CDT.B1.2 | Proposal for Steering Committee as Complexity | It is proposed that the cost of the steering committee (for the ERP implementation which is being processed in the model) should not be accounted for, as this is usually a business cost and not an ERP project cost. However, it should be accounted for as a complexity. | | |

The main feedback from the validation sessions is as follows:

- It was strongly recommended by Company J that out of the eleven complexity dimensions which were initially proposed, five of these should be made mandatory and three optional dimensions should be selected from the remaining six dimensions. The company advised that this will enable a manageable and simple complexity assessment process. It will also closely follow the analytical hierarchy process (AHP) requirement of having a manageable (seven) number of elements for comparison, even though there is one additional complexity proposed for C-REACT.

- Company B suggested that for customisation complexity, the type of customisation and number of items customised should be defined as part of the guidelines for the complexity of resource and assessment costing tool (C-REACT).
- It was suggested that change management should be incorporated in C-REACT as a complexity, and not just as an activity in the ERP implementation WBS. This way, the complexity of the change management process can be assessed by management. An example of change management complexity would be the legal requirements of the locations where the change will occur.
- Company J requested that each complexity dimension should have a maximum of three complexity types for ease of identification, assessment and manageability.
- Expert 26 from Company M recommended that the complexity resource assessment and costing tool should have the capability to demonstrate that complexity is exponential and not linear.

#### 5.3.1.5 Developed Complexities

The output of the conceptual validation was a taxonomy of complexity dimensions, for which complexity types had been defined. The developed taxonomy of complexity dimensions is depicted in Figure 5-8, and a complexity breakdown structure incorporating the complexity dimensions and types is presented in Figure 5-9.

The first level of the CBS represents the complexity dimension taxonomy and the second level represents the complexity types for each dimension. This complexity breakdown structure will be embedded in C-REACT. As the amount of complexity associated with each complexity type is not always directly measurable, the complexity types are further decomposed into cost drivers. This will serve the purpose of measuring the amount of complexity associated with each complexity type, and form the basis for estimating the cost of the complexity. The meaning of each cost driver is defined as a set of three criteria which are used to score complexities.


**Figure 5-8:** Developed Complexity Dimensions

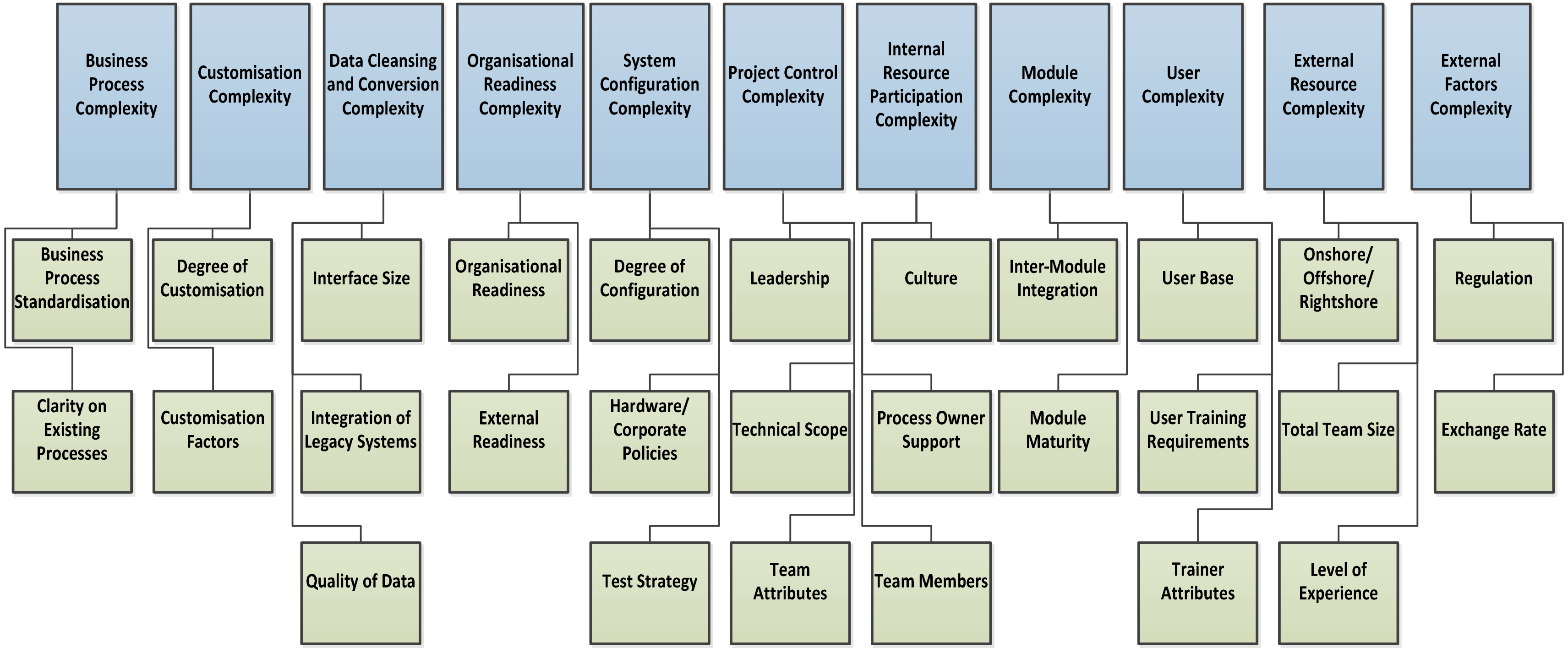



**Figure 5-9:** Complexity Breakdown Structure

### 5.3.2 ERP Implementation Cost Drivers

The first step in defining a set of ERP cost drivers which would be embedded in the C-REACT frameworks, involved a combination of a comprehensive literature review, semi-structured interviews with six organisations, one ERP expert, surveys with twenty-one participants, and the researcher's SAP implementation experience.

#### 5.3.2.1 Phase 1 – Familiarisation of ERP Cost Drivers

The research methodology which was applied in defining ERP cost drivers for C-REACT follows the same steps as the methodology applied in complexity definition. This process is discussed in Section 5.3.1.1.

**Literature Review Findings**

The researcher conducted detailed literature review on cost elements which drive the cost of an ERP whole life cycle project. The cost drivers studied would be narrowed down to understand the drivers for complexity, and the drivers for project activities and resources. Some of the cost drivers studied were grouped into five categories from literature review as depicted in Figure 5-10. Each of the categories contained five cost drivers, except for the application category which composed of four cost drivers. The cost drivers in this category do not apply to the ERP implementation stage.

The only cost drivers which apply to this stage in the operations category are level of customisation and changes made to ERP system. One of the key findings in the cost driver literature review is that research has not yet defined a comprehensive list of cost drivers for ERP complexity. This supports the findings that there is not a comprehensive ERP complexity costing technique defined in research. Based on this research gap, the researcher produced a set of cost drivers which were presented to participants for their feedback, in interviews and online surveys.

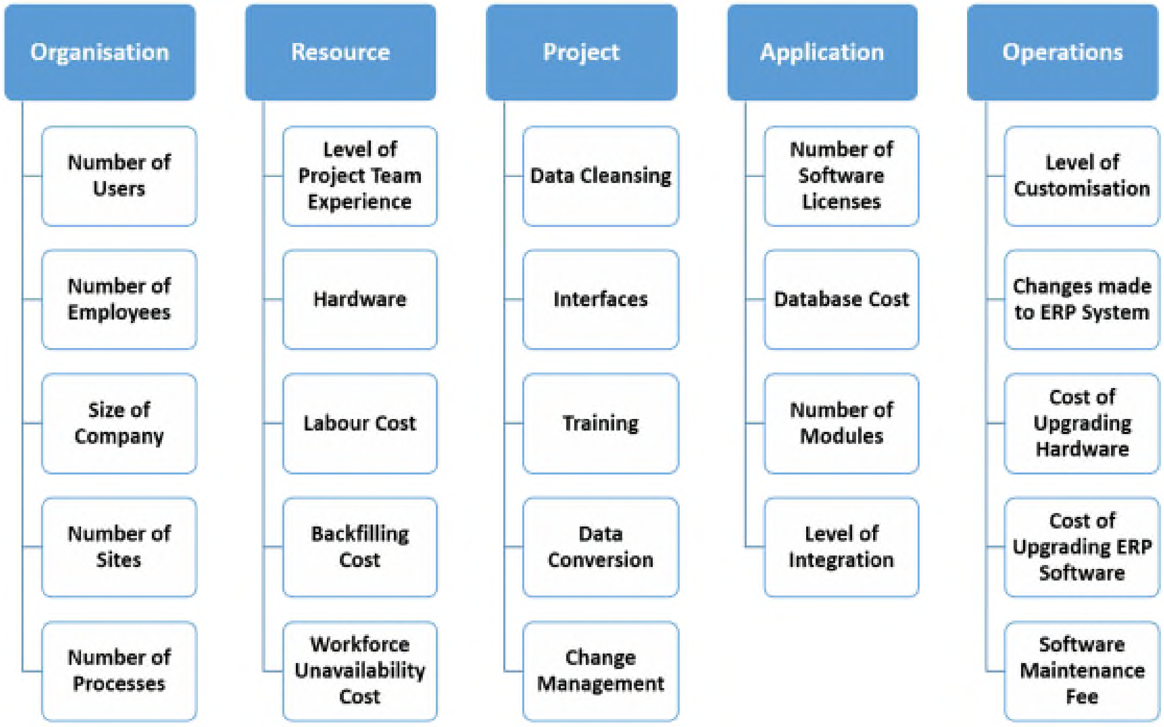



**Figure 5-10:** ERP Cost Drivers

**Interviews and Online Surveys**

The approach adopted in conducting interviews and online surveys for cost drivers follows the same methodology for ERP complexities as discussed in Section 5.3.1.1. The findings from the literature review, and the researcher's work experience were used to develop the initial set of cost drivers. The purpose of conducting these interviews and online surveys was to ascertain a set of cost drivers which will be embedded in the C-REACT framework. The two questionnaires which were used to obtain feedback on ERP complexities in interviews and online surveys were also used to present questions for feedback on ERP cost drivers. These questionnaires are described in Section 5.3.1.1.

### 5.3.2.2 Phase 2 – Development of an ERP Cost Driver Taxonomy

Part A of the first questionnaire, as well as the online questionnaire, presented semi-closed questions on cost drivers to the participants. Fifty-one cost drivers were provided, from which the interviewees were required to select the top twenty, and the online participants were asked to select the top ten. These cost drivers were obtained from the literature review presented in Chapter 2. The online participants were given a lower number of options in order not to discourage them from completing the questionnaire. The fact that it is an online survey suggests that the questions should be kept to a minimum and as concise as possible for the purpose of speed. In the case of the interviewees, it was easy for them to select the top twenty cost drivers, as the questionnaire was designed to discuss specific project scenarios. Hence, the cost drivers in these scenarios flowed during discussions with the researcher over the preceding questions. The end of the question on cost drivers provided an 'Other' option for the participants to specify cost driver which had not been catered for in the original options. Twenty-one participants responded to the question on cost drivers, and a total of eight interviewees selected some of the options on this question. The total number of interviewees and participants was twenty-nine.

Out of all the options that were selected by the online participants and interviewees, the top fifteen were ranked for use in C-REACT, based on the total number of participants. The selected cost drivers and their corresponding rankings are illustrated in Table 5-7.

**Table 5-7:** Cost Drivers from Interviews and Online Survey

| Cost Drivers | Number of Interview Participants | Online Survey Participants | Total Number of Participants | Percentage | Ranking |
|---|---|---|---|---|---|
| Software License | 7 | 19 | 26 | 90% | 10 |
| Hardware | 8 | 17 | 25 | 86% | 9 |
| Cost of Database | 7 | 17 | 24 | 83% | 8 |
| Data Cleansing & Conversion | 8 | 16 | 24 | 83% | 8 |
| Training | 7 | 16 | 23 | 79% | 7 |
| Labour Cost | 6 | 14 | 20 | 69% | 6 |
| Size of Company | 6 | 13 | 19 | 66% | 5 |
| Interfaces | 7 | 12 | 19 | 66% | 5 |
| Network Infrastructure | 5 | 13 | 18 | 62% | 4 |
| Third Party Product | 3 | 14 | 17 | 59% | 3 |
| Configuration | 6 | 11 | 17 | 59% | 3 |
| Type of Company | 2 | 14 | 16 | 55% | 2 |
| Scope Creep | 4 | 12 | 16 | 55% | 2 |
| Change Management | 3 | 13 | 16 | 55% | 2 |
| Slow Decision Making | 5 | 11 | 16 | 55% | 2 |
| Backfilling Project Resources | 4 | 11 | 15 | 52% | 1 |
| Testing | 4 | 11 | 15 | 52% | 1 |

#### 5.3.2.3 Phase 3 – Refinement of ERP Cost Driver Taxonomy

The refinement workshops followed the development of the initial cost driver taxonomy. It was conducted through two individual meetings for each participating organisation, and a WebEx workshop with all the participants. The details of the participants of this workshop are provided in Section 5.3.1.3. The researcher presented the cost drivers which were obtained from interviews and online surveys, to participants of the refinement workshop. The purpose of this workshop was to review the cost drivers for applicability to the refined complexities, and suitability for the C-REACT framework.

In the workshops, all participants agreed that it is essential that the complexities are not only identifiable, but also measurable for cost estimation purposes. In order to satisfy this requirement, cost drivers must be defined to enable linking to the complexities. As the complexities had been classified into dimensions and types, the cost driver was the third level of the hierarchy and directly attached to the complexity types. Some of the complexity types were converted to cost drivers. One of the key cost driver refinements was related to items of customisation, data conversion and interfaces. These areas are all concerned with development which requires a different skillset from standard configuration because it involves coding. The cost of development items are already traditionally estimated according to their complexity levels. Additionally, complexity types had been defined for these development items. Therefore, the participants recommended that all such complexity types should be further classified into cost drivers which reflect the level of complexity for each of the relevant complexity types. Therefore, the complexity types interface size, degree of customisation, and conversion should all be further classified into the following cost drivers:

- number of high complexity level interfaces
- number of medium complexity level interfaces
- number of low complexity level interfaces
- number of high complexity level conversions

- number of medium complexity level conversions
- number of low complexity level conversions
- number of high complexity level items to customise
- number of medium complexity level items to customise
- number of low complexity level items to customise.

The rationale behind this classification is that each development item possesses different characteristics at different levels. It is a significant driver for cost as its level of complexity determines what it will cost. For instance, five low complexity level interfaces will not cost the same as five high complexity level interfaces. Therefore, in the event that the complexity of resource and assessment costing tool does not differentiate between the interfaces to be developed in terms of their complexity, all interface developments will cost the same.

#### 5.3.2.4 Phase 4 – Conceptual Validation of Cost Drivers

This section presents the conceptual validation of cost drivers, which was part of the fourth phase of the research methodology. This activity involved the same participants as those involved in the conceptual validation of complexities as described in Section 5.3.1.4 which also outlines the details of the participants. The conceptual validation for complexities also included cost drivers. Therefore the same process and medium was applied in both instances.

One of the requirements from the conceptual validation process on cost drivers was provided by Expert 11 from Company J which is a reputable ERP consultancy. Expert 11 who is an ERP project manager, advised that each complexity type should be further decomposed into cost drivers which will determine the measurement for the complexity types. Additionally, under the circumstances where there is an excess of three complexity types, the excess may be represented as cost drivers for measuring the complexity types.

Expert 15 from Company C proposed that the cost drivers be classified into direct influence and indirect influence cost drivers. The former means that the metric for the relevant cost driver can directly measure an activity in the WBS. And the latter means that there is no direct relationship between the cost driver and any activity in the WBS. This classification will enable the parametric cost estimation which is adopted in defining the effort required to execute a project activity. This cost estimation method is implemented in C-REACT and discussed in Chapter 8.

The initial set of cost drivers which were presented to the participants of the conceptual validation was mostly quantitative. Therefore, Expert 11 from Company J suggested that the set of cost drivers should be more elaborate and should also be enabled to measure complexities which are not of a quantitative nature. Although the researcher had employed the use of complexity levels in measuring the initially produced cost drivers, Expert 11 from Company J recommended that these complexity levels be further determined by qualitative complexity criteria. All participants were in agreement with this proposal.

#### 5.3.2.5 Developed ERP Cost Drivers

A final taxonomy of eighty-one cost drivers was developed in the refinement and conceptual validation process for cost drivers. These cost drivers were classified into four dimensions which indicate their characteristics. An example of this classification is provided in Table 5-8. The complete taxonomy of eighty-one cost drivers is presented in Appendix B.2. These cost drivers have been categorised by complexity type in Table 5-9. The developed cost drivers are characterised by the nature of their measurement and their influence on project activities. Therefore, they are described as either quantitative or qualitative in relation to measurement, and either direct or indirect influence in terms of their correlation with project activities. Quantitative cost drivers enable a direct measurement by number or size. For instance, the cost driver number of standard business processes will have a quantity directly assigned to it. In relation to qualitative cost drivers, they are not measured by number or quantity. For instance, the cost driver, definition, which is correlated with the complexity type clarity of business process, cannot be quantified. It is concerned with the clarity of the business process definition. Therefore, qualitative measurement techniques are applied to qualitative cost drivers.

**Table 5-8:** Developed Cost Drivers

| Cost Driver | Quantitative | Qualitative | Direct Influence | Indirect Influence |
|---|---|---|---|---|
| **Number of standard business processes** | • | | • | |
| **Roles** | | • | • | |
| **Industry-Specific experience** | | • | | • |
| **Likelihood of additional regulation** | | • | | • |

**Table 5-9:** Linking Cost Drivers to Complexity Types

| Complexity Type | Cost Driver |
|---|---|
| **Clarity of Existing Processes** | roles, information, definition, performance, controls, documentation, level of automation |
| **Business Process Standardisation** | number of standard business processes |
| **Level of Experience** | industry-specific experience, number of implementation cycles, experience of this version and module of ERP, proven implementation methodology, proven methodology toolset |
| **Onshore/Offshore/Rightshore** | onshore/offshore/rightshore |
| **Total Team Size** | total team size |
| **Degree of Customisation** | number of low level items to customise, number of medium level items to customise, number of high level items to customise |

| Complexity Type | Cost Driver |
|---|---|
| **Customisation Factors** | type of customisation, longevity of customisation, definition of customisation requirements |
| **Interface Size** | number of low level interfaces, number of medium level interfaces, number of high level interfaces |
| **Integration of Legacy Systems** | integration of previous systems |
| **Quality of Data** | number items to cleanse, number of interrelationships, number of low level conversions, number of medium level conversions, number of high level conversions, quality of “old” data, corporate master data management effectiveness |
| **Degree of Configuration** | number of items to configure |
| **Hardware/Corporate Policies** | deployment approach, thick / thin client, software versions (Java, IE, Chrome, etc.), cloud vs. on-premise, hardware cost (if on premise), hardware SLA – uptime, hardware SLA – resilience, hardware SLA – backups |
| **Test Strategy** | availability of automated tools (Loadrunner, QTP), |
| **User Base** | total number of professional users (not concurrent), total number of self-service users (not concurrent), number of user roles |
| **User Training Requirements** | approach - train-the-trainer, approach - electronic (CBT) |
| **Trainer Attributes** | approach - external vs. internal, number of trainers available, cost of training facilities |
| **Organisational Readiness** | experience with complex information systems, business-as-usual ERP support team readiness, degree of buy-in from business, “what's in it for me?” |
| **External Readiness** | external stakeholder readiness, regulatory impact |
| **Leadership** | changes in senior management during project, governance approach, business changes |
| **Technical Scope** | number of standard items to change, number non-standard items to change |
| **Team Attributes** | assumption management, team working environment/geography, team language |
| **Culture** | organisation culture |
| **Process Owner Support** | SME (Subject Matter Expert) availability, process owner availability, sponsor strength |

| Complexity Type | Cost Driver |
|---|---|
| **Team Members** | percentage of time for internal resource, incentivisation, change management experience, ERP implementation experience |
| **Module Maturity** | numbers of large/medium sized customers using module, years since initial deployment, number of changes since last module upversion, reliability (size indicator in that it measures the number of logical paths in a module) and maintainability (measures the degree to which a module contains unstructured constructs) |
| **Inter-Module Integration** | level of required integration between modules, interface control standards between modules, integration technology used |
| **Regulation** | likelihood of additional regulation |
| **Exchange Rate** | project currency |

## 5.4 Complexity Definition Process

In this section, the developed complexities are defined. Figure 5-11 presents an overview of complexity. This provides an understanding of the developed complexities and their areas of impact within the ERP environment.

The complexity overview in Figure 5-11 is composed of five sections:

- **Complexity dimensions** – these are the eleven complexity dimensions which were developed in the conceptual validation of complexities
- **Areas of impact** – these are the consequences of the complexity dimensions. There are five areas of impact which are also used to define the states of complexity using the difficult to use, understand, manage, implement and potential to increase (UUMII) complexity model.
- **Categories of complexity measurement and characteristics** – these are the characteristics which determine complexity.
- **Ambiguity in complexity** – this is composed of uncertainty and emergence which cause ambiguity in complexity. Ambiguity is one of the key causes of complexity and is often inevitable.

- **Cost** – all the other four sections of the framework indicate a continuation of cost increase as the factors in these areas materialise.

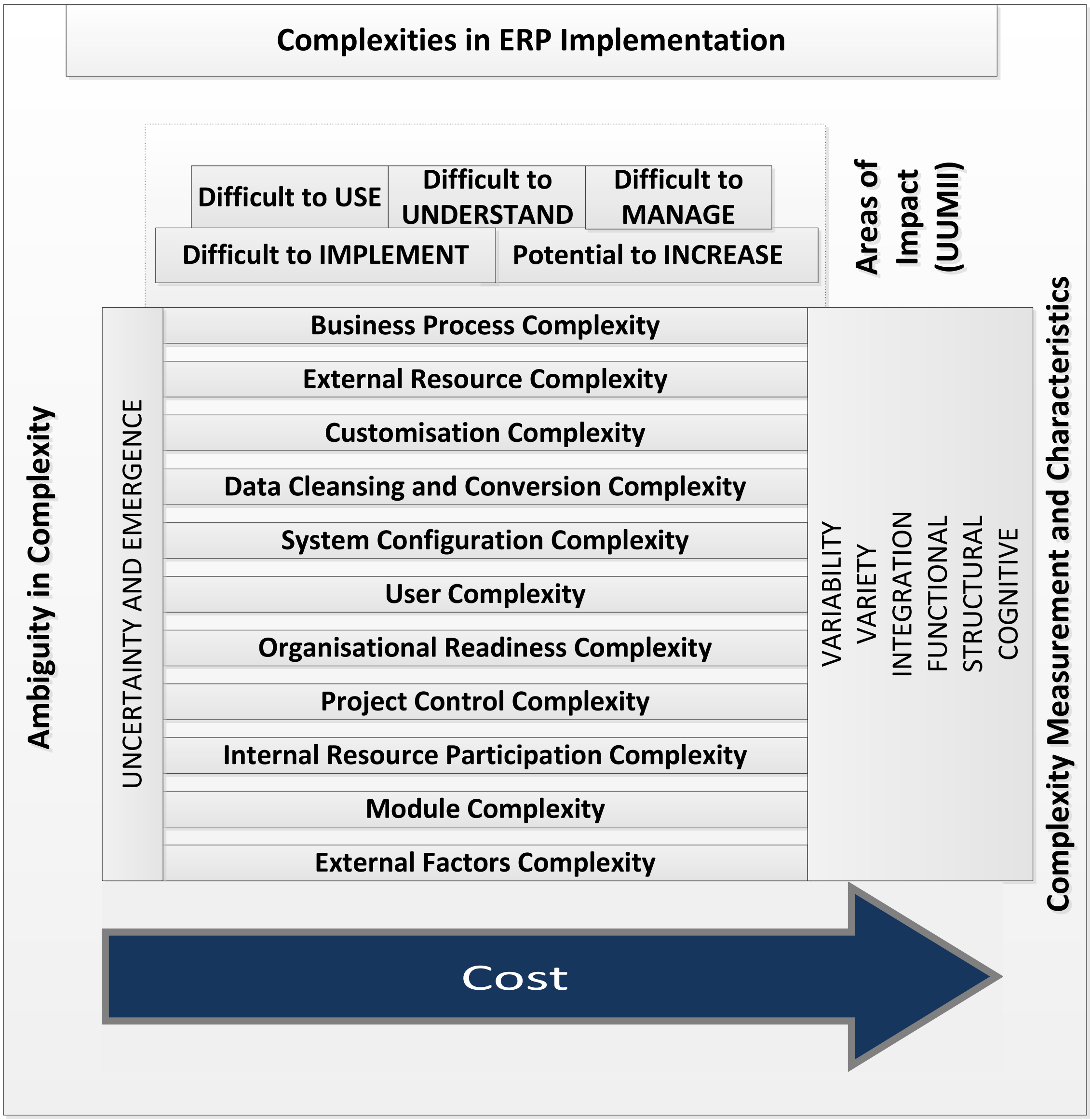



**Figure 5-11:** Overview of Developed Complexities

An understanding of complexities in an ERP environment enables effective assessment and costing of the identified complexities. In Section 5.4.1, the complexity dimensions and associated types, and cost drivers are defined. In Section 5.5 where the effect of the developed complexities on the ERP environment is discussed, the classification of ERP complexity dimensions into categories is illustrated. Furthermore in this section, the impact of the proposed complexities on cost is discussed.

### 5.4.1 Definition of Developed Complexities and Cost Drivers

Eleven complexity dimensions were developed in the conceptual validation session. Each of these complexity dimensions was decomposed into a maximum of three complexity types. Eighty-one cost drivers were developed by the researcher and industrial collaborators, and these were categorised by complexity type. The definition of each complexity dimension, as well as its correlation with complexity types and their associated cost drivers is provided in Appendix B.1

## 5.5 Impact of Complexities in ERP Environment

This section discusses the impact of the proposed complexities on ERP implementations by classifying these complexities as dimensions, as illustrated in the overview depicted in Figure 5-11. These dimensions are business process complexity, external resource complexity, customisation complexity, data cleansing and conversion complexity, system configuration complexity, user complexity, organisational readiness complexity, project control complexity, internal resource participation complexity, module complexity, and external factors complexity. Additionally, in this section, the researcher has used five indicators to identify the impact areas of complexity. The classification of ERP complexity into impact areas enables the easy understanding and effective management of complexities. The effect of the complexities on categories of complexity measurement and characteristics are also discussed based on the overview in Figure 5-11. Furthermore, the effect of ambiguity on complexity is discussed through uncertainty and emergence. Finally, the impact of complexity on cost is discussed.

### 5.5.1 Impact Areas

In the event of an ERP system implementation, several areas of the organisation, the solution and project are affected by complexity. It is for this reason that ERP complexity increases. Therefore, a thorough understanding and knowledge of these areas will enable the early identification and assessment of potential ERP complexity prior to implementation. The overview in Figure 5-11 depicts the areas which are impacted by the developed ERP complexities by using five complexity indicators. These indicators are derived from the definition of complexity which is adopted for this research in Sections 2.4 and 5.3.1.1 according to Sessions (2011) and Jacobs (2013) definitions. Sessions (2011) has specified that a system is complex if its characteristics make it difficult to use, implement, understand and/or manage. He further asserts with Jacobs (2013) that complexity increases with an increase in elements within the system. Therefore, the indicators are specified as; (1) difficult to use, (2) difficult to understand, (3) difficult to manage, (4) difficult to implement, and (5) potential to increase. These indicators form the UUMII (use, understand, manage, implement and increase) complexity model defined by the researcher. UUMII enables the identification of the state of an ERP solution in the presence of complexity. The UUMII Complexity Model is presented in Figure 5-12. The impacts of the developed complexity dimensions are illustrated in Table 5-10 using the UUMII indicators.

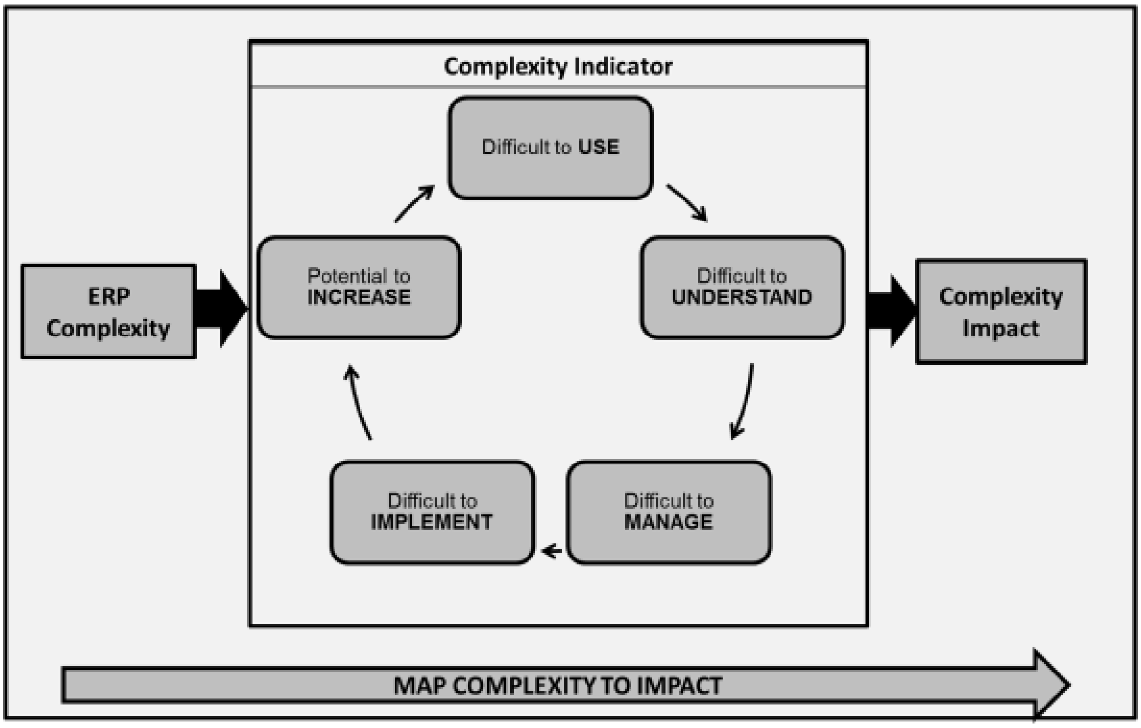



**Figure 5-12:** The UUMII Complexity Model

**Table 5-10:** The Linkage of ERP Complexity to Areas of Impact

| Complexity Impact Areas | Complexity Dimensions |
|---|---|
| **Difficult to use** | Customisation Complexity, Business Process Complexity, System Configuration Complexity, Module Complexity, Data Cleansing and Conversion Complexity |
| **Difficult to understand** | Customisation Complexity, System Configuration Complexity, Data Cleansing and Conversion Complexity, User Complexity |
| **Difficult to manage** | Customisation Complexity, Organisational Readiness Complexity, Project Control Complexity, User Complexity, Module Complexity, System Configuration Complexity |
| **Difficult to implement** | Customisation Complexity, Organisational Readiness Complexity, System Configuration Complexity, External Factors Complexity, Internal Resource Participation Complexity, Data Cleansing and Conversion Complexity, External Resource Complexity |
| **Potential to increase** | Customisation Complexity, System Configuration Complexity, Data Cleansing and Conversion Complexity, Business Process Complexity |

Although, the number of complexity dimensions in each area of impact should act as an indication of the weight of the impact, the actual complexity dimensions in a more populated impact area might not be as critical as the complexities in a less populated impact area. Every complexity is critical, although some more than others. Hence, it is the responsibility of an experienced ERP expert to judge the ultimate importance of ERP complexities against each other. Furthermore, correlating the effect of each complexity on another will add to the weight of importance for each complexity dimension.

### 5.5.2 Complexity Categories

The characteristics of complexity are presented as categories in the overview presented in Figure 5-11. These categories provide an indication of the characteristics which compose a complexity and span all complexities, as specified in Table 2-4. There are six categories illustrated in the framework; variety, variability, integration, functional, structural and cognitive. In Table 5-11, the complexity categories are linked to the proposed complexity dimensions through ticks.

**Table 5-11:** Mapping Complexity Dimensions to Complexity Categories

| **Complexity Dimensions** | **Variety** | **Variability** | **Integration** | **Functional** | **Structural** | **Cognitive** |
|---|---|---|---|---|---|---|
| Business Process Complexity | | | √ | √ | | |
| External Resource Complexity | √ | | | | | √ |
| Customisation Complexity | √ | | √ | √ | √ | |
| Data Cleansing and Conversion Complexity | √ | | √ | | √ | |
| System Configuration Complexity | √ | | | | | |

| Complexity Dimensions | Variety | Variability | Integration | Functional | Structural | Cognitive |
|---|---|---|---|---|---|---|
| User Complexity | √ | | | | | √ |
| Organisational Readiness Complexity | √ | | | | | |
| Project Control Complexity | √ | √ | | √ | | |
| Internal Resource Participation Complexity | √ | | | | | √ |
| Module Complexity | | | | | | |
| External Factors Complexity | | √ | | | | |

### 5.5.3 Ambiguity, Uncertainty and Emergence in Complexity

Ambiguity is one of the causes of complexity (PMI, 2014). It is defined by Haas (2009) and PMI (2014) as a state of being unclear and not knowing what to expect. Ambiguity is introduced by uncertainty and emergence (PMI, 2014). These causes of complexity are defined in Chapter 2.

In relation to the complexity definition overview, it is illustrated that uncertainty and emergence span the complexity dimensions. This means that they can appear at any time in any of the dimensions. These causes of complexity make it difficult to estimate and plan accurately for ERP implementations. Hence it is imperative to incorporate an uncertainty cost in the complexity cost, as this covers some level of uncertainty which may arise. Complex ERP components with variety, variability and cognitive characteristics are most likely to give rise to uncertainty and emergence. Some complexities are difficult to predict. Certain complexities also emerge unexpectedly and there is no way of accounting for this kind of complexity. The current practice is to incorporate contingencies into ERP implementation project estimates, but there is a lack of structure for this practice. Therefore, the ERP resource complexity costing framework of this research presents a structured approach for quantifying uncertainty in complexities.

### 5.5.4 Cost

The overview in Figure 5-11 indicates that as complexities arise and increase, the associated cost increases. An increase in complexity always induces an increase in cost, as discussed in Chapter 2. Cost is the most important aspect of an ERP implementation, as it is required for the implementation to occur. But it must be estimated almost accurately, if not accurately. In order to enable a good ERP complexity cost estimate, the potential complexities and associated causes must be correctly identified and thoroughly understood in order to accomplish a structured and accurate assessment. Uncontrolled complexity can lead to uncontrolled cost increases, which can in turn, result in a failed or cancelled implementation. Therefore, controlled complexity is necessary for controlled cost.

## 5.6 Summary

This chapter presented an overall framework for this research in Section 5.2. The framework is based on findings from literature review, interaction with industry and the researcher's SAP work experience. The framework is classified into two phases which constitute the scheduling of project activities and resources, identification of ERP complexity, assessment of ERP complexity, and dynamic costing through simulation of ERP complexity.

In Section 5.3, the methodology for structuring the list of complexities and associated cost drivers was presented in order to highlight the steps which were followed within this process. Four steps were applied in the definition of complexity process; (1) phase 1 – familiarisation of ERP complexities, costing and project life cycle, (2) phase 2 – development of a taxonomy of complexities, cost drivers, project activities and resources, (3) phase 3 – refinement of ERP complexities, costing and project life cycle, and (4) phase 4 – conceptual validation of the refined list of ERP complexities, costing and project life cycle. The interaction with several organisations from various industries was also presented.

A process for defining and understanding the proposed complexities was presented in Section 5.4. Section 5.5 presents the impact of the proposed complexities on ERP implementation environment. The effect of each complexity dimension on the impact areas is discussed, the classification of complexity dimensions into categories of complexity characteristics is presented, the effect of uncertainty and emergence on ERP implementations is discussed, and the impact of ERP complexities on cost is highlighted.

The following chapter presents the ERP Resource Complexity Costing framework which has been built and implemented in a tool.

# 6 ERP IMPLEMENTATION WORK BREAKDOWN STRUCTURE DEVELOPMENT

## 6.1 Introduction

This chapter follows on from the overall ERP complexity framework development discussed in Chapter 5. The methodology which was adopted in the development of the project activities within which the developed complexities exist, and the resources who experience these complexities, is described in this chapter. It is a continuation of the methodology presented in Chapter 5.

ERP implementation schedules often overrun. Hence, it is imperative that the correct project methodology is adopted. Additionally and most importantly for the purposes of this research, it is essential that the complexities which are inherent in ERP implementations are accounted for in the project methodology. This enables the identification, assessment and costing of ERP complexities.

The developed project activities and resources are presented using a work breakdown structure (WBS). The WBS will be embedded in the complexity of resource and assessment costing tool (C-REACT) which is the product of this research. A work breakdown structure is used in C-REACT as the foundation for costing the complexities, as the base cost for each resource is calculated upon the activity they are engaged in. Once the complexities within the relevant activities have been assessed, a complexity number for each activity is added as a percentage to the resource base cost. The result of this addition generates a resource complexity cost. This chapter fulfils the research objective to define a work breakdown structure for ERP implementation activities and resources for which the complexity cost will be estimated

In Section 6.2, the methodology for defining the developed ERP implementation project activities and resources is described. This chapter is summarised in Section 6.3.

## 6.2 Methodology for Defining the ERP Implementation WBS

The specification of ERP project whole life cycle stages, phases and activities is discussed by several authors. However, the subject of using the project activities and resources of an ERP implementation to assess and cost ERP complexities is not mentioned in the literature review. Therefore, the researcher adopted a methodology that will enable the definition of a comprehensive work breakdown structure (WBS) which will include the project activities and resources upon which the identification, assessment and costing of ERP resource complexities is established.

The development of the WBS was an iterative process, and sometimes occurred alongside the development of complexities. The process commenced with a literature review on ERP project methodologies. Thereafter, the researcher presented the outcome of the literature review in combination with her work experience to industry and individual experts for their opinions. This information gathering process was conducted through interviews. The results of these interviews were demonstrated to industry collaborators who participated in the conceptual validation conducted in this research. The participants refined the WBS until a final version was developed for implementation in C-REACT.

### 6.2.1 Phase 1 – Familiarisation of ERP Project Life Cycle

The first step in defining a work breakdown structure (WBS) which will be embedded in C-REACT involved gaining a detailed understanding of ERP project methodologies through literature review. Another task which contributed significantly to this step is that the researcher conducted semi-structured interviews with two organisations and one ERP expert, for feedback on project methodology. Finally, the researcher's SAP implementation experience contributed to defining the WBS. The focus of the literature review was on ERP whole life cycle stages, ERP implementation phases and activities, and ERP project resources.

#### 6.2.1.1 Literature Review Findings

A detailed literature review was conducted in order to understand the stages within an ERP whole life cycle project, as well as the phases which constitute the implementation stage. The knowledge and understanding gained from this review will enable the researcher to discern the project activities within which the developed ERP complexities arise.

**ERP Whole Life Cycle Project Stages, Phases and Implementation Activities**

In order to gain an understanding of ERP whole life cycle stages, implementation phases and activities with allocated resources, the researcher combined experience obtained from her SAP implementations with literature review. The key findings from the literature review are that:

- each ERP whole life cycle stage is a huge undertaking in its entirety and the implementation stage is the most costly whole life cycle (WLC) stage, with the most complexity; therefore, the researcher focused this research on the implementation stage.
- the most suitable ERP project whole life cycle stages to use as a basis for understanding ERP project methodology are;
    - ➢ needs identification, package evaluation and selection, implementation, post go-live support, and maintenance (Iba, 2006).
- The ERP implementation stages defined by Iba (2006) are based on the ASAP (Accelerated SAP) project methodology defined by SAP, the first and most established ERP software vendor. Therefore, the most suitable ERP implementation phases to apply as the platform upon which C-REACT is built are;
    - ➢ project preparation, business blueprint, realisation, final preparation, and go-live and support (Iba, 2006).

Another key finding of the literature review is that various ERP implementation methodologies have been defined by ERP software vendors and their implementation partners. However, an approach for complexity identification, assessment and costing is not built into these methodologies.

#### 6.2.1.2 Interviews and Online Surveys

The next step from the literature review was to conduct semi-structured interviews to gather the relevant data for ERP implementation activities and resources. Two organisations and a freelance ERP expert participated in the semi-structured interviews for confirming the ERP implementation activities, the average cost of each activity, and the number of resources involved in each activity. Expert 1 from Company A which is an oil organisation participated in the interviews. Expert 1 was the chief information officer of the company, but acted as the project manager for the ERP implementation. Expert 4 who was the IT manager for business change in his organisation, Company E, was also involved in the interviews. Expert 4 also played the role of project manager for an ERP implementation conducted by Company E, an entertainment organisation. The third participant was Expert 10, an ERP functional consultant who was freelance. A preliminary interview was conducted with each participant, which lasted for 30 minutes. Thereafter, each interview with each participant lasted for an hour. Questionnaire B, which was briefly described in Chapter 5 was used to gather the relevant data on the ERP activities, cost, schedule and resources required for an ERP implementation. The key questions for collating the required data are outlined in Figure 6-1.

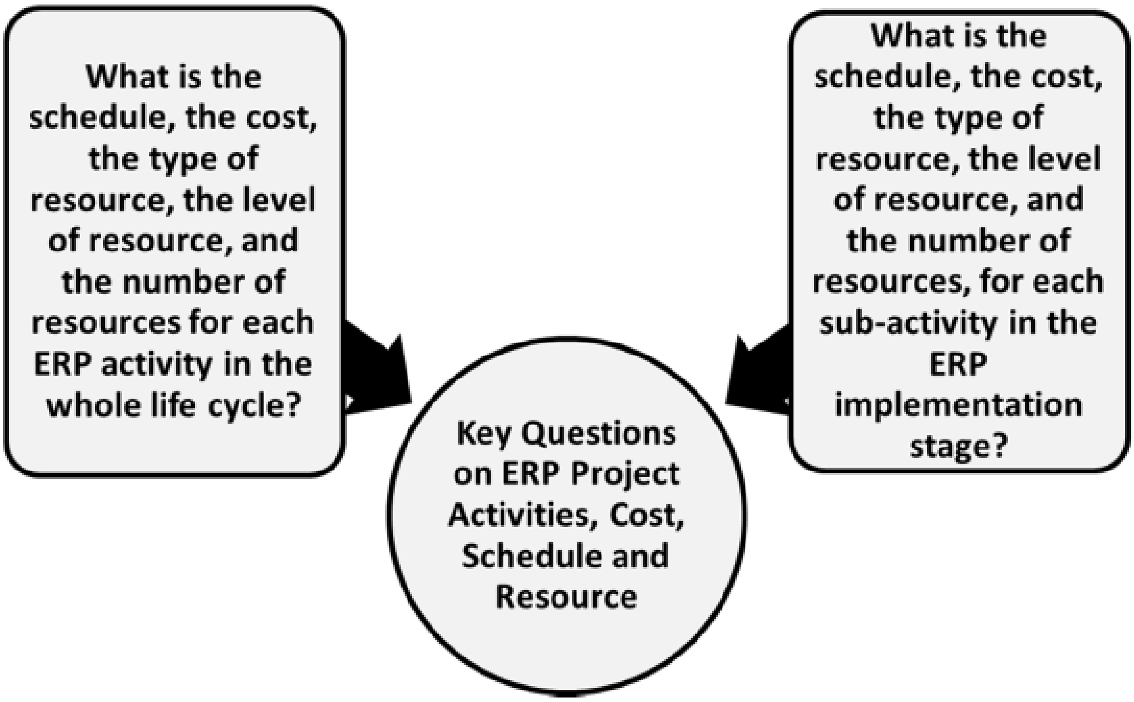



**Figure 6-1:** Key Questions on ERP Project WLC and Implementation Activities

In questionnaire B, two tables were presented for specification of the activities and resources in the WLC activities and implementation activities. The first table contained the activities in an ERP whole life cycle. Although the stages of an ERP whole life cycle project are confirmed by the interview participants, this research ultimately focuses on the project activities in the implementation stage and the resources allocated to each activity. The second table constituted the activities in an ERP implementation stage. Thereafter, the researcher presented six resource types in questionnaire B, based on her SAP work experience. The resource types are project manager, module lead, subject matter expert, trainer, functional consultant, and technical consultant. The interview participants were required to specify which WLC and implementation activity each resource is involved in.

### 6.2.2 Phase 2 – Development of Project Activities and Project Resource Types for ERP Implementation

The initial work breakdown structure of ERP activities and list of ERP resources which were produced from the interviews, are discussed in this section.

**Linking ERP Project Resource Types to Project Activities**

In response to the questions in questionnaire B, the same participants who were involved in the semi-structured interviews specified the resource types which should be deployed to each ERP implementation activity. They also specified the level of experience required for each resource type.

### 6.2.3 Phase 3 – Refinement of ERP Implementation WBS

The next step was to refine the initial table of the project activities and resources in order to define a more comprehensive work breakdown structure (WBS) for ERP implementations. A total of thirty-five project activities were produced based on the activities defined in Chapter 2. The resource types were redefined. The researcher split the subject matter expert (SME) role to Functional Subject Matter Expert (FSME), Technical Subject Matter Expert (TSME) and Key User. The FSME will take on the role of imparting business domain knowledge to the functional consultant, and will be responsible for supporting the functional aspect of the system when it becomes operational. The TSME will take over the technical work from the technical consultants. As for the key user, they will be responsible for training the rest of the users of the system.

The project management resource type was also decomposed into External Project Manager (EPM) and Internal Project Manager (IPM). The essence of this distinction will enable an accurate costing, as the IPM will most likely be paid a salary, whilst that the EPM will be on an hourly or a daily rate.

In the course of refining the ERP project activities and resources, the researcher defined the mapping of the initial taxonomy of complexity cost drivers to the refined project activities. The elements were linked based on the researcher's ERP implementation experience, and the semi-structured interviews conducted.

The initial taxonomy of complexity dimensions and their associated complexity types were mapped to the refined WBS of project activities. This occurred prior to establishing the developed complexity taxonomy. The complexity types were presented as complexity cost drivers. The relationship between the complexity cost drivers and the project activities is presented in a WBS complexity matrix in Chapter 7. Each complexity in the WBS complexity matrix is linked to the project activity where it is inherent.

As the complexity increases, so does the cost of the resources engaged in the relevant project activity. Complexity increases exponentially, as discussed in Chapter 2. Due to its nature of interrelatedness, a complexity in one part of a system enacts a complexity in other related parts of the system. Each of these emergent complexities also introduces complexities in other areas. This can lead to an uncontrollable situation, as there is no standard method to determine the number of complexities generated as a result of one complexity. A clear picture of the impact of complexity on each project activity, will support an organisation in reducing complexity, thereby reducing the cost of implementation. It also aids them to assess the skillset of the resources hired onto the project, as they affect every aspect of the project.

### 6.2.4 Phase 4 – Conceptual Validation of ERP Project Activities and Resources

The conceptual validation of the ERP implementation WBS was the next step after refining the WBS activities and resources. The validation process was very thorough and detailed. The essence of the conceptual validation was to produce a final WBS which will be suitable for incorporation in the framework for the complexity of resource and assessment costing tool (C-REACT). The validation was conducted with experts from industry as outlined in Section 5.3.1.4. However, the only participants from the complexity conceptual validation who were not involved in this process are Expert 26 from Company M and Expert 27. Both these participants are IT complexity experts, and did not have the relevant experience to validate an ERP WBS. The time spent on the conceptual validation of the WBS activities and resources is incorporated in the time spent in the complexity and cost driver validation. All three elements (ERP complexities, cost drivers and WBS) were validated concurrently.

The methodology which was adopted in conducting the conceptual validation is depicted in Figure 6-2.

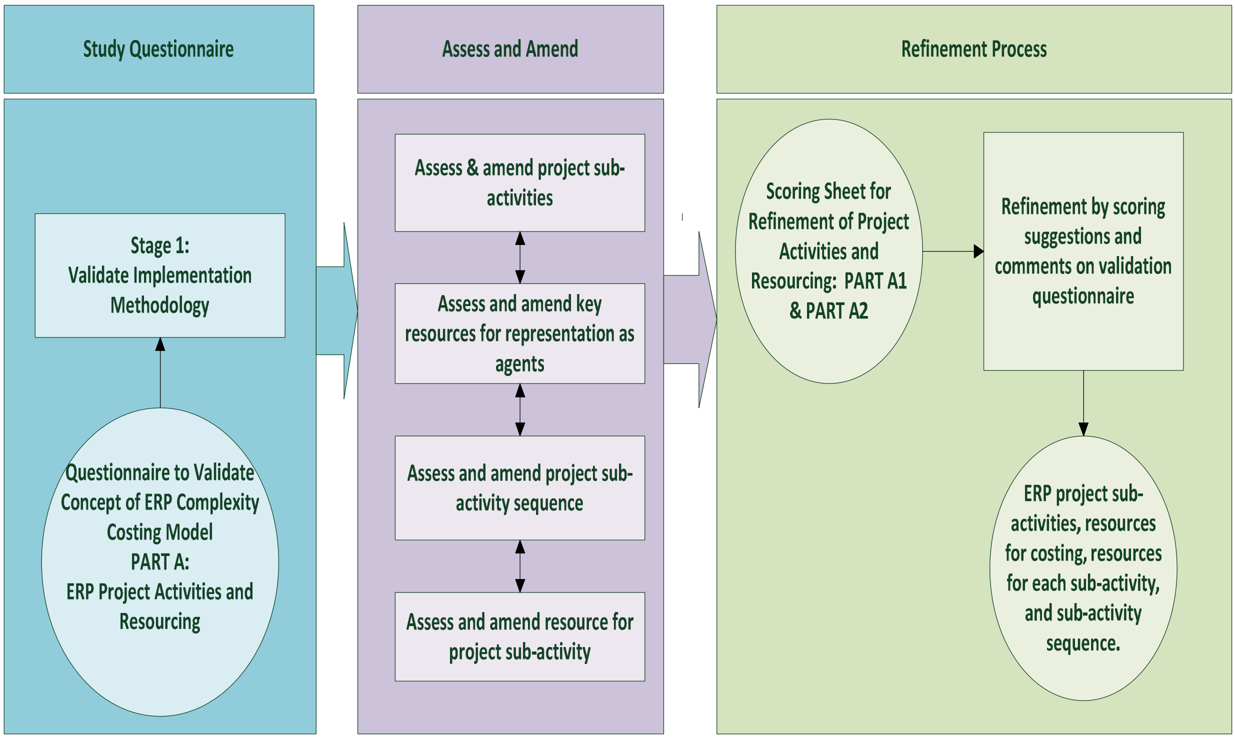



**Figure 6-2:** Methodology for Conceptual Validation

A questionnaire was used to facilitate the conceptual validation of the ERP work breakdown structure. This questionnaire is provided in Appendix A.2. Part A of the questionnaire focused on evaluating the refined list of the ERP project activities and resources. The initial step of the validation process involved studying and discussing the items of the questionnaire. Thereafter, the items which were highlighted for assessment were evaluated and amended accordingly. Certain critical suggestions and proposals were made and taken into the final step of the conceptual validation, which was an iterative refinement process. The essence of this process was to assess the views of all the participants over suggestions which were made.

The questionnaire which was used to assess the refined list of project activities and resources was composed of 8 tasks. The key validation areas are highlighted in Figure 6-3. The validation also involved the participants working in groups, especially in the process of defining the activities which compose the proposed WBS.

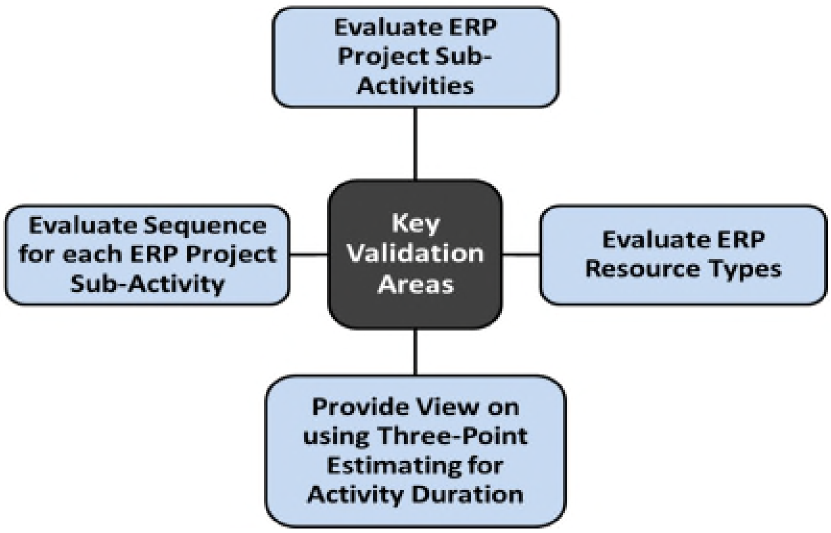



**Figure 6-3:** Key Validation Areas

#### 6.2.4.1 Validation Feedback

The participants of the conceptual validation were honoured to be involved in the process of defining the WBS, which would be developed in C-REACT. These validators were very impressed with the concept of using a work breakdown structure to determine the complexity of an ERP implementation project. They admitted that although some organisations attempt to assess complexity in the costing of an ERP implementation, a structured framework does not exist for this process. Therefore, the costing of an ERP implementation is ambiguous and arbitrary. The participants conceded that C-REACT will not only aid in the costing of the resource complexity, it will enable a thorough assessment of the resources, the activities and the complexities. The knowledge acquired from this assessment will; (1) prepare a potential ERP adopting organisation for a future ERP implementation, and (2) enable a reasonable and controlled implementation cost. Therefore, they advised that the elements of the proposed WBS be rigorously analysed, verified and defined as a collective effort across all the organisations involved in the validation. The WBS will be the platform upon which the complexity assessment and cost estimation of this research is based. Hence, the project activities and resources must be correctly defined for a satisfactory complexity assessment and cost estimation.

**A Generic Work Breakdown Structure**

Company C and Company J advised that the refined WBS is not sufficiently generic, and should incorporate a methodology which will cater for SAP, Oracle and other ERP solutions. In the event that the WBS is left in its current state, it will only be useful for SAP implementations. However, they cautioned that it is pivotal to understand that certain sub-activities are specific to a particular ERP project; therefore a generic WBS might not fit all ERP implementations.

**Costing Idle Resources**

Company C adamantly proposed that idleness in the WBS when used in C-REACT should not be accounted for. Otherwise the idle resources will have to be off-boarded during the period of the activities for which they are idle. This will mean on-boarding them again to commence other activities at the scheduled time. The on-boarding process may lose up to two weeks of productivity, as it could take this amount of time to introduce the resource into the system again. It was suggested that the framework be automated to seek activities that a resource could engage in instead of being idle. Other participants proposed that the C-REACT framework be developed to cost idleness, and allocate the responsibility of optimising the resource re-allocation to the project manager. The purpose of the framework is to cost resource complexity, as opposed to resource allocation.

**Incorporating Critical Path Analysis in the WBS**

Company C proposed that the critical path needs to be introduced into the project work breakdown structure for a more accurate calculation of duration for the dependencies (the activities that are linked). The introduction of critical path will be influential in not over-allocating resources. However, Company B requested that all participants should recall that C-REACT is not intended for project planning. Therefore, processing the critical path in the tool is unnecessary. Although it was subsequently suggested that functionality be developed which may be used to pre-specify the activities in a critical path for further actions in the tool. These further actions will be executed in the event that the complexity in the activity in question is high. This option is discussed as part of the tool implementation in Chapter 8. It was also proposed that in the event that C-REACT matures in the future, it might be practical at that time to automate a critical path function in it.

### Specification of Activity Duration using Three-Point Estimating

The use of three-point estimating for the duration of the project sub-activities in C-REACT was perceived and reported to be very practical by most of the participants. Their reason for supporting three-point estimating is because it caters for any uncertainty in the execution of the activity. However, one participant cautioned that given the vast differences in scale between projects, it may be more pragmatic to implement three single point estimates (small/simple project, medium project, large/complex project) with some up front selection criteria (number of modules, number of countries, number of companies).

### Incorporating Change Management Activity in WBS

In terms of the proposed change management activity, the proposal by the participants was that the WBS should be business-focused with an emphasis on change management and readiness. On the contrary, although all the participants were strong advocates of incorporating change management in C-REACT, some of them proposed that it should be treated as a complexity and not as an activity because the latter will require associated activities. Another reason behind this proposal is that change management is normally run as a separate exercise from project management. Therefore, it is practical to address it as a complexity.

### Specification of Resource Quantity for each Activity

It was discussed that it is a challenge to specify number of resources for the duration of each project activity because this depends on the scope of implementation and scale of the adopting organisation. For instance, a finance and HR solution in a single site company will require far fewer resources than a finance/HR/procurement/manufacturing solution in a global company with operations in 150 countries. Therefore, all the participants decided that the user of C-REACT will be responsible for inputting the relevant number of resources based on the type and scale of project in question. An option may also be presented by C-REACT to provide the user with an out-of-the-box number of resources per module.

**Guidelines for WBS**

Company C suggested that guidelines and a framework should be created to aid the user in their inputs of implementation activity duration and critical path.

**Customising the WBS**

It was proposed that the WBS should be customisable so that it may be tailored to different projects as deemed necessary.

**Specific Changes to Activities and Resources**

At the initial stage of the conceptual validation, Company C, Company J, and Company B advised that the following new activities should be added to the WBS:

- Plan Resources to Provide Support
- Benefits Realisation
- Change Management
- Analyse AS-IS Model
- Design User Access Rights
- Develop Test Plans
- Create Sandbox and Development Environment
- Build User Access Rights
- Create Draft Training Manual
- Develop Test Plans Final
- Create QA Environment
- Train UAT Team
- Create Final Version of Training Manual
- Train Users
- Create Production Environment
- Data Migration and Validation

- Parallel Runs Test
- Launch ERP Functionality/System
- Hand System Over to BAU Team

The newly proposed resource types are:

- Technical Support Analyst
- Change Manager
- Benefits Realisation Consultant
- Steering Committee
- Solutions Architect
- Project Auditor
- Quality Assurance Consultant

The resource type for the steering committee was eventually eliminated from the WBS, as its members do not have a cost impact on the project activities. According to the validators, the steering committee holds a meeting on a monthly basis in a lot of projects. From the researcher's experience, this holds true. Therefore, apart from the project managers, the members of the committee are not involved in daily project activities. The other resource type which was eliminated from the WBS is the Project Auditor. The rationale behind this decision is that this role sparsely engages in the implementation activities. Therefore, the impact of this role on complexity and cost is limited.

The final decision concerning resource types was to incorporate only resources with a significant complexity and cost impact on the implementation project.

**Other Suggestions for the WBS**

The participants of the conceptual validation proposed other specific changes to the WBS as follows:

- The name Build AS-IS Model has been proposed to be changed to Analyse AS-IS Model. The reason for this is that the AS-IS model is not normally built, but analysed. Also the focus should be on the TO-BE model; hence building the AS-IS model will be time-consuming.

- It was suggested that the piloting of each process design is not necessary in the WBS; this task is not always fulfilled in every ERP implementation project. Hence it should be optional.
- The conceptual validation participants suggested that workflows be added to the work breakdown structure.
- The general consensus on the parallel runs activity in the WBS is that they are mainly conducted in payroll implementations. Hence these tests are not mandatory for other functions and also not always conducted in payroll implementations. It was proposed that even though this activity remains in the methodology, it should be transferred from the Go-Live activity to the Final Preparation activity.
- Company J suggested that the WBS be enabled to cater for isolated projects, even though in the real world, projects are not always isolated.
- The participants from Company J suggested that the name of the activity Blueprint be changed to Design. The reason for this suggestion is that the name Design is seemingly more flexible and allows changes later on, unlike the name Blueprint which implies a finality of the design.

Most of the changes proposed for incorporation in the WBS were fulfilled by the researcher. However, other changes were not fulfilled because they either do not suit the purpose of the complexity of resource and assessment tool (C-REACT), or would require a longer period of time to develop in the tool.

#### 6.2.4.2 Developed ERP Implementation Project WBS

The refined WBS activities and resources were refined iteratively by all the participants of the conceptual validation. Midway through validation, Company C produced their company-specific ERP implementation methodology for use as the WBS for C-REACT. They expressed their interest in being a major contributor to the development of C-REACT. The participants from this company were adamant about C-REACT utilising a very detailed methodology which would suit several ERP implementations.  Company C uses this methodology to implement several ERP solutions, especially SAP and Oracle, and it incorporates 148 activities.  This methodology was further refined to produce the developed work breakdown structure for ERP implementations, and it is presented in Figure 6-4.  This developed WBS comprises of 53 activities.

The rationale behind the developed WBS is that the other participants raised their concern about the number of activities in Company C's methodology, cautioning that this might deter potential users of C-REACT.  They proposed a compact WBS to enable ease of use.  Company C agreed to this proposal, and as a result, the participants and the researcher embarked on a refinement process of the proposed methodology.  The agreement amongst all the participants was to form groups of activities for some of the interrelated sub-activities.  The final WBS constitutes 53 activities.  The definition for each of the developed activities is provided in Appendix C.  The final developed resource types are presented in Figure 6-5.

The next step after evaluating the resource types was the assessment of the project activity sequence.  The final sequence number for each developed project activity is presented within brackets in Figure 6-4.

The proposed activity sequence indicates that some activities are conducted simultaneously, whilst the majority of activities are conducted sequentially.  This sequence will be used in the dynamic costing of the ERP resource complexity which will be simulated using agent based modelling.  The dynamic costing is presented in Chapter 8.


**Figure 6-4:** Developed ERP Implementation Work Breakdown Structure

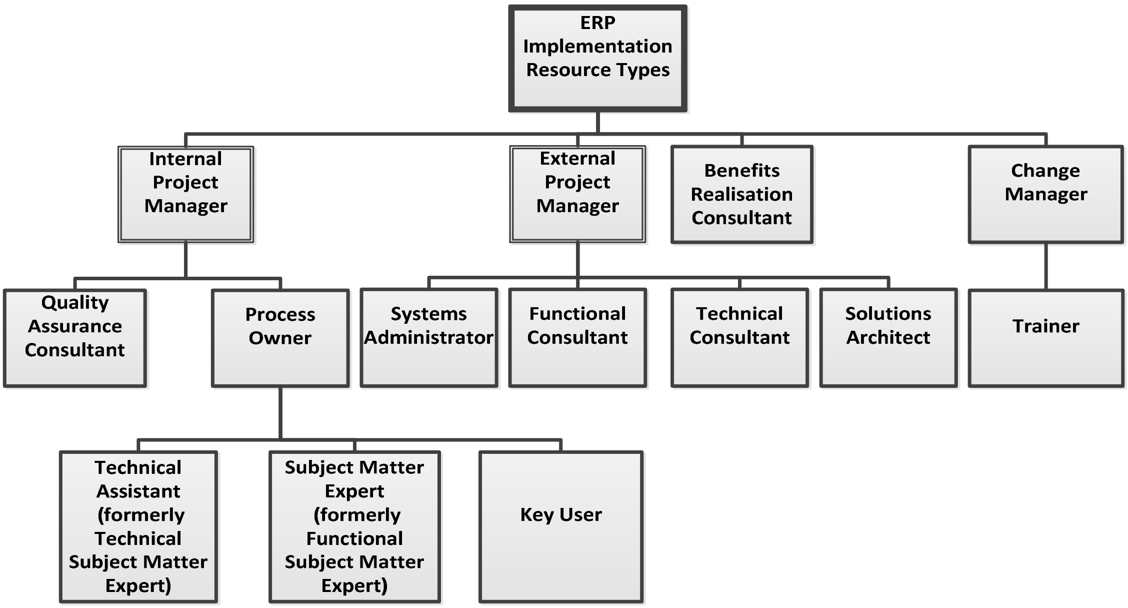



**Figure 6-5:** Proposed Resource Types from Conceptual Validation

## 6.3 Summary

In Section 6.2, the methodology for structuring the work breakdown structure which is embedded in C-REACT was presented. The WBS incorporates the ERP implementation project activities and resources. Four steps were applied in the definition of the WBS and implementation resources. The first step was phase 1 of the methodology, which entailed the familiarisation of the ERP whole life cycle, including the implementation stage. The second step was phase 2, which involved the development of the initial project activities and resources. Step 3 which is known as phase 3 in the methodology constituted the refinement of the project activities and resources. And finally, the fourth step which is phase 4 of the methodology discussed the conceptual validation of the refined ERP project activities and resources. The suggestions and proposals which were made by the validation participants were detailed in this section. Furthermore, a newly developed WBS which will be embedded in C-REACT was illustrated in this section. The following chapter presents the framework development for the ERP complexity assessment phase of C-REACT.

# 7 ERP COMPLEXITY ASSESSMENT FRAMEWORK

## 7.1 Introduction

This chapter focuses on the complexity identification and assessment for the ERP implementation stage. The outline of this chapter is presented in Figure 7-1. In addition to the literature review of this thesis, industrial collaborators involved in this thesis have expressed concern over the inefficient and costly ERP implementations which lead to failure for adopting organisations. These inefficiencies and expensive implementations are caused by inherent complexities in the project, which have not been anticipated. The lack of anticipation does not allow for the cost of these complexities to be accounted for in the implementation cost estimate. This challenge drives the need for the identification and assessment of complexity which in turn, enables effective complexity control and costing. However, in order to identify and assess the complexity, it must be thoroughly understood. This chapter presents a framework which assesses complexities in ERP implementations. The framework aids ERP adopting organisations in anticipating, controlling, reducing and costing implementation resource complexity in the needs identification stage. Furthermore, this framework is useful to the ERP implementation consultancy at the stage of bidding for the implementation project. It serves as a common platform upon which both the ERP adopter will collaborate their complexity anticipation, control and costing efforts. The framework is embedded in a software tool which is developed in Microsoft Excel. The tool is called Complexity of Resource and Assessment Costing Tool (C-REACT).

C-REACT addresses complexity from a resource perspective. It enables to identify and specify the complexities which are likely to be encountered by the resources on the project. This empowers an organisation to anticipate ERP resource complexities and costs. Resources can help to reduce or increase complexity, depending on their level of experience and scale of complexity. The knowledge of complexities and costs for each resource provides an organisation with clarity of every resource’s involvement in the implementation project, and their value to the project. Literature review has exposed a gap in this area, and industrial collaborators are in need of a framework for complexity assessment and costing. Therefore, C-REACT fills the research gap, and fulfils ERP industry needs. An early view of implementation complexity allows an organisation to prepare early, thereby enabling control of the potential complexities in order to achieve a successful implementation. Therefore, this chapter fulfils the research objectives; (1) develop a technique for assessing ERP complexity, and (2) design and develop a framework for assessing ERP implementation complexities to support in identifying, understanding and preparing for potential ERP implementation resource complexities

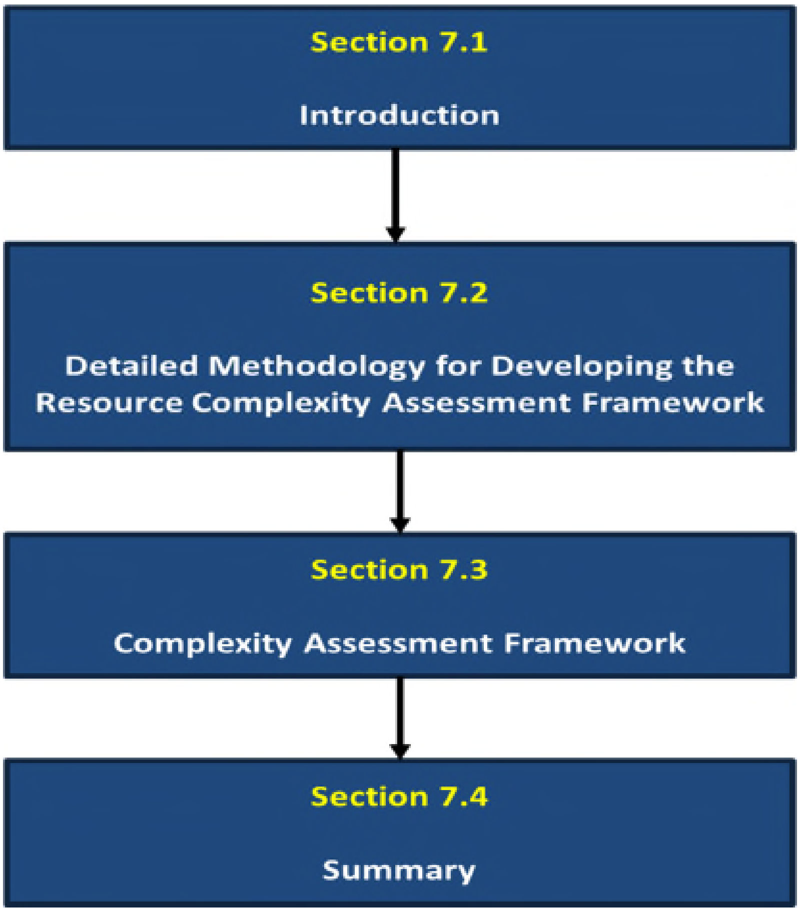



**Figure 7-1:** Outline of Chapter 7

## 7.2 Detailed Methodology for Developing the Complexity Assessment Framework

As highlighted in literature review, improving software quality and project controllability requires controlling the software complexity by measuring the related aspects. This same principle applies to ERP implementations. The four effects of software metrics are; (1) understanding the project and resources, (2) forecasting and estimating the unknown, (3) evaluating the situation of the project, and (4) controlling by analysing the deviation between the real software development and development plans, and detecting where the anomalies could occur and adjusting the plan to achieve control.

The achievement of software measurement requires a process. Three phases in software measurement are defined in literature review as define, collect and analyse. These three phases have been adapted by the researcher in defining the complexity assessment framework.

A framework was developed for assessing the complexities which would be encountered in an ERP implementation. The outcome of the assessment will be used by industry for guidance in understanding, anticipating, controlling and costing complexity. In order to build this framework, a method was adopted in defining its components. The methodology is presented in Figure 7-2.

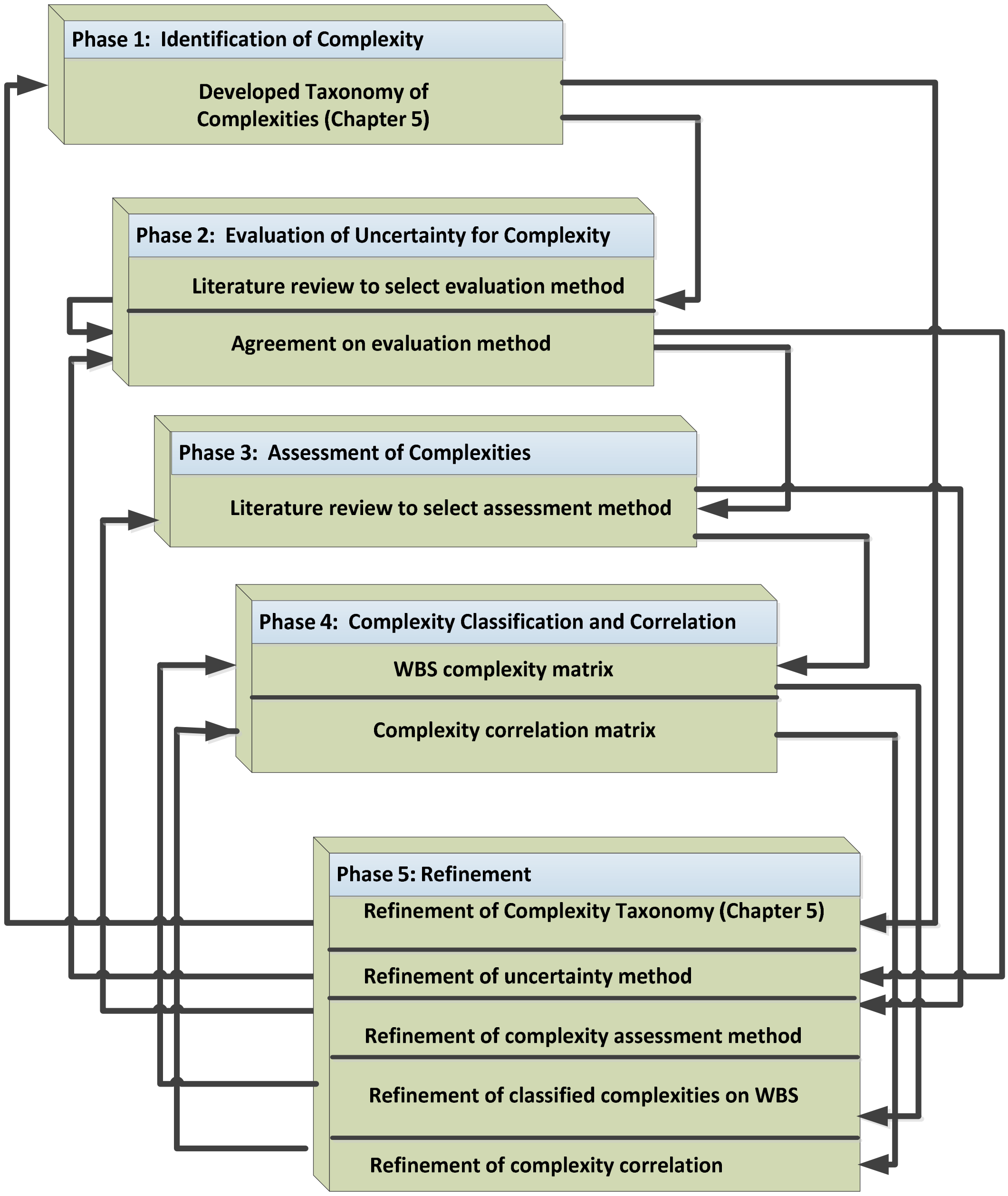



**Figure 7-2:** Methodology for Developing ERP Complexity Assessment Framework

The methodology is composed of five phases; identification of complexity, evaluation of uncertainty for complexity, assessment of complexities, complexity classification and correlation, and refinement.

### 7.2.1 Phase 1 – Identification of Complexity

This phase uses the developed complexity taxonomy which was defined in Chapter 5 as its input. A pre-defined taxonomy of complexities were validated by industry experts and a refined and developed taxonomy was produced by the participants of the conceptual validation discussed in Chapter 5. The methodology for deriving this complexity taxonomy is presented in chapter 5.

### 7.2.2 Phase 2 – Evaluation of Uncertainty for Complexity

As part of this phase, literature review was conducted in order to derive a method for evaluating the uncertainty of the complexities specified in C-REACT. These complexities would be selected from the developed taxonomy produced in phase 1. However, the estimates must be assessed in relation to uncertainty, as they would be produced by experts under circumstances with limited data in some cases. A comparison of various uncertainty assessment methods was conducted by Refsgaard *et al.* (2007). These methods are data uncertainty engine (DUE), expert elicitation, extended peer review, inverse modelling, Monte Carlo analysis, numeral unit spread assessment pedigree (NUSAP), scenario analysis and sensitivity analysis. Based on these comparisons, the researcher selected the NUSAP scheme for the uncertainty evaluation of the complexities which are identified for assessment and costing. NUSAP was chosen for the following reasons:

- It aids researchers to evaluate the materials which they study and use, with ease as it enables ambiguous interpretations to be clearly conveyed.
- It utilises both quantitative and qualitative dimensions of uncertainty and allows these dimensions to be presented in a structured manner
- Most importantly, it may be applied in complex models and assumptions even though model-based assessment and foresight of complex environmental problems is limited by many different types of uncertainty (Van der Sluijs *et al*., 2003). This research addresses complex situations

in ERP implementations which constitute numerous uncertainties. Therefore selecting NUSAP is suitable for C-REACT.

The NUSAP scheme is applied by using its five qualifiers (numeral, unit, spread, assessment and pedigree) to qualify quantities (Van der Sluijs *et al*., 2005). However, for the purposes of this research, the pedigree qualifier will be applied. Pedigree conveys an evaluative account of the production process of information, and indicates different aspects of the underpinning of the numbers of the knowledge used. It is expressed by means of a pedigree criteria to assess these different aspects, which involves qualitative expert judgment. Each special sort of information has its own aspects that are crucial to its pedigree. The NUSAP method was presented to the experts involved in conceptual validation as discussed in chapter 5.

The second scheme which was proposed for uncertainty evaluation is a manual scoring approach. This method uses the same scoring numbers as the pedigree matrix in NUSAP. However, it eliminates the three pedigree criteria. The rationale behind this proposal is to enable organisations to score the uncertainty of complexities in a flexible manner. The manual scoring scheme was suggested by Expert 17 who is a programme manager from Company B, an aerospace and defence organisation.

### 7.2.3 Phase 3 – Assessment of Complexity

In this phase, a literature review was also conducted in order to adopt a method for the assessment of complexities. The essence of this scheme is to enable the measurement of complexity by quantifying it, and using it as an input into the costing process.

The process of assessing the complexities will ideally occur in a group setting and measurement will be conducted amongst a set of complexities by ranking one against the other for prioritisation. A multi-criteria decision making (MCDM) technique was adopted for this purpose. Toloie-Eshlaghy *et al*. (2011) define multi-criteria decision making as involving the making of preference decisions (for instance, evaluation, prioritisation and selection) from the available alternatives which are characterised by multiple, usually conflicting criteria. Multi-criteria decision making has been used substantially used over the last several decades and is applied in solving both theoretical and practical problems. The researcher studied the comparison of MCDM techniques which was conducted by Velasquez and Hester (2013), as illustrated in Table 7-1. The analytical hierarchy processing (AHP) technique was the preferred and selected scheme for this research for the following reasons:

- it is applied to address the ambiguities involved in the assessment of ERP system alternatives and relative importance weightings of attributes (Wei *et al*., 2005)
- it has been applied to complex problems of a quantitative and qualitative nature which is similar to the topic and focus of this research
- it has been applied in a wide variety of areas including planning, selecting a best alternative, resource allocation and resolving conflicts

**Table 7-1: Subset of MCDM Methods (Adapted from Velasquez and Hester, 2013)**

| Methods | Advantages | Disadvantages | Areas of Application |
|---|---|---|---|
| **Multi-Attribute Utility Theory (MAUT)** | Takes uncertainty into account; can incorporate preferences. | Needs a lot of input; preferences need to be precise. | Economics, finance, actuarial, water management, energy management, agriculture |
| **Analytic Hierarchy Process (AHP)** | Easy to use; scalable; hierarchy structure can easily adjust to fit many sized problems; not data intensive. | Problems due to interdependence between criteria and alternatives; can lead to inconsistencies between judgment and ranking criteria; rank reversal. | Performance-type problems, resource management, corporate policy and strategy, public policy, political strategy, and planning. |
| **Case-Based Reasoning** | Not data intensive; requires minimal maintenance; can | Sensitive to inconsistent data; requires many cases. | Businesses, vehicle insurance, medicine, and engineering |

| Methods | Advantages | Disadvantages | Areas of Application |
|---|---|---|---|
| **(CBR)** | improve over time; can adapt to changes in environment. | | design. |
| **Fuzzy Set Theory** | Allows for imprecise input; takes into account insufficient information. | Difficult to develop; can require numerous simulations before use. | Engineering, economics, environmental, social, medical, and management. |
| **Simple Multi-Attribute Rating Technique (SMART)** | Simple; allows for any type of weight assignment technique; less effort by decision makers. | Procedure may not be convenient considering the framework. | Environmental, construction, transportation and logistics, military, manufacturing and assembly problems. |

### 7.2.4 Phase 4 – Complexity Classification and Correlation

This phase predominantly entailed defining a method for classifying the activities within which the assessed complexities manifest, for the purpose of costing. In order to cost the complexities encountered by resources, the project activities which they have worked in must be identified. Therefore, the developed complexities should be mapped to their relevant project activities. A work breakdown structure (WBS) complexity matrix was developed for this purpose. This WBS complexity matrix was presented to the conceptual validation participants outlined in Chapter 5 for their feedback. All the participants agreed to the implementation of a matrix for classifying the complexities within ERP project activities. A sample of the WBS complexity matrix is presented in Table 7-2. Each cell which maps a complexity to an activity is indicated by inputting the value ‘1’ in the cell. This serves as an indicator of complexity presence. The WBS complexity matrix would also serve the purpose of reporting the amount of complexity in each activity.

An example of a classified WBS activity with complexities is analyse business process, as indicated in Table 7-2. It is indicated in the matrix that the complexity types; clarity of existing process, level of experience, onshore/offshore/rightshore, and organisational readiness, amongst other indicated complexity types, exist in the analyse business process activity. This is a crucial activity where all the TO-BE (future) processes which are implemented in an ERP solution, are defined. In the event that the business processes are not clearly defined, they would be incorrectly configured and have other knock-on effects in the system. Should the level of experience of the external resources be low, then it is very likely that the business processes will not be clearly defined. As for the onshore/offshore/righshore complexity, if there is a mixture of onshore and offshore consultants defining the business processes, this could cause a communication problem as a result of language and time zone differences. In terms of organisational readiness, defining business processes with subject matter experts (SME) and users who are not ready to change the way they work, will cause a difficulty for the consultants to establish clearly defined processes.

**Table 7-2:** WBS Complexity Matrix Definition

| Complexity Type / Activity | Clarity of Existing Processes | Business Process Standardisation | Level of Experience | Onshore/Offshore/Rightshore | Total Team Size | Degree of Customisation | Customisation Factors | Interface Size | Integration of Legacy Systems | Quality of Data | Degree of Configuration | Hardware / Corporate Policies | Test Strategy | User Base | User Training Requirements | Trainer Attributes | Organisational Readiness | External Readiness | Leadership | Technical Scope | Team Attributes | Culture | Process Owner Support | Team Members | Module Maturity | Inter-Module Integration | Regulation | Exchange Rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analyse Business Process | 1 | | 1 | 1 | | | | | | | | | | | | | 1 | 1 | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Develop Interface Program | | | | | | | | 1 | 1 | 1 | | | | | | | | | | 1 | 1 | | | | 1 | 1 | 1 | 1 |
| Configure System | 1 | | 1 | 1 | | | | | | | 1 | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

The participants of the conceptual validation agreed to the contents of the matrix. Expert 11, a SAP project manager from Company J, a reputable and global ERP consultancy advised that he is confident that the WBS complexity matrix would be used on future ERP implementation projects. They conceded that had this matrix existed previously, they would not have experienced the challenges presented to the organisation in their current project.

In phase 4, a second method was defined in order to demonstrate the additional complexity types which would emerge in the presence of the classified complexity types in the WBS complexity matrix. This method would require the development of relationships amongst the complexity types. Therefore the researcher developed another matrix, which is known as the complexity correlation matrix (CCM) using a design structure matrix (DSM) format. The relationships in the CCM give rise to exponential ERP implementation costs, which are often unexpected. Hence they are referred to as hidden costs. A complexity correlation matrix also informs an organisation of the potential additional complexities which have not been classified in the WBS complexity matrix. Therefore in the event that the actual resource complexity cost is higher than the resource complexity cost estimated by C-REACT, the reason will most likely be because of the emergent complexities which have not been quantified, as indicated in the CCM. The complexity correlation matrix is illustrated in Table 7-4.

The experts from Company B and Company C conducted the first validation of the complexity correlation matrix and made the relevant adjustments. Company B is an aerospace and defence organisation, and Company C is a reputable ERP implementation consultancy. Initially, a fishbone diagram was used to identify the relationships amongst complexity types. Thereafter, the correlations were transformed into a design structure matrix for implementation in C-REACT. The correlation between the complexity type, clarity on existing process and other complexities is illustrated in Figure 7-3. The rationale behind these correlations is described in Table 7-3. A description of each correlation is provided in the note section for each relevant cell in the matrix, in C-REACT.

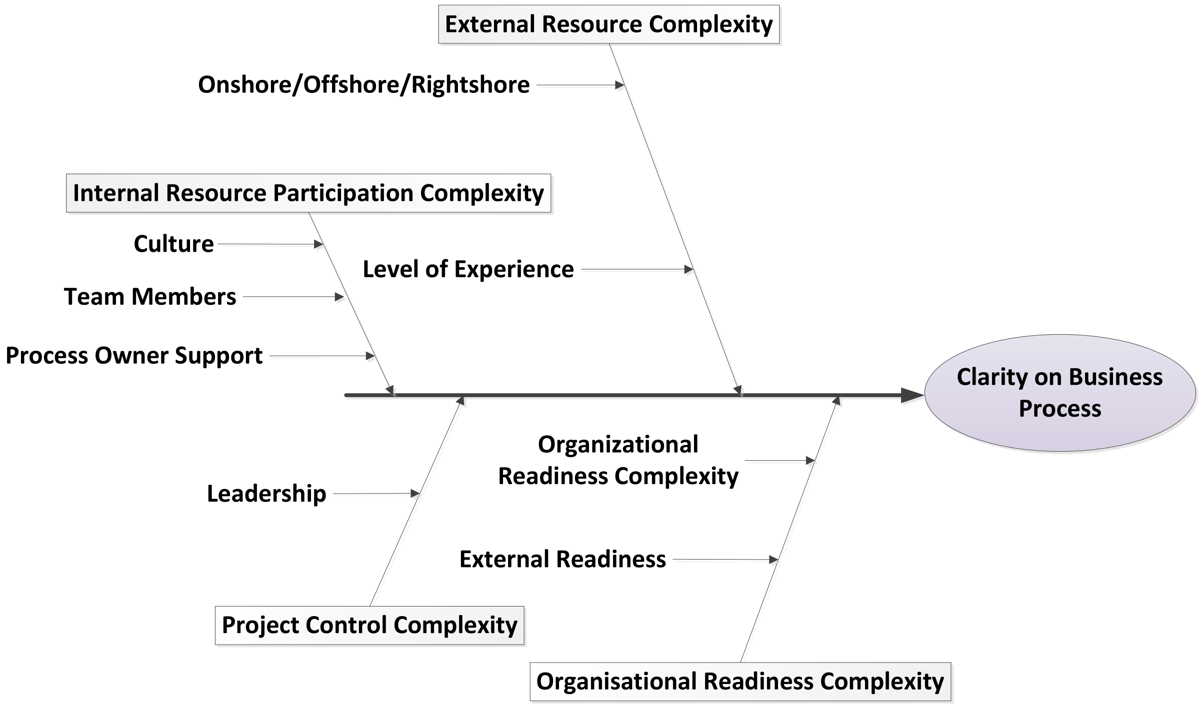



**Figure 7-3:** Correlation for Clarity on Existing Processes

The type of correlation (positive or negative, or both) is explicitly illustrated in the relevant cells of the complexity correlation matrix as follows:

- Positive is denoted with the number ‘1’
- Negative is denoted with ‘-1’
- Both positive and negative are indicated as ‘-1/1’

The complexity correlations are not quantified. They are only highlighted in order to provide awareness of potential complexity types which could cause an increase in complexity cost. This awareness supports decision-making and scenario analysis for complexity control and reduction.

**Table 7-3:** Description of Clarity on Existing Process Complexity Correlation

| Cause of Clarity on Existing Processes | Rationale for Cause | Correlation Type |
|---|---|---|
| **Level of Experience** | The less the number of implementation cycles and industry-specific experience a functional consultant has, the poorer the definition of business processes. | Positive |
| **Onshore/Offshore/Rightshore** | The more offshore teams there are and the more languages spoken by the different team, the poorer the definition of the business processes are likely to be. | Negative |
| **Culture** | If organisation does not embrace change due to a strong culture which does not have a fit with that of the consultants, then they may resist defining the business processes clearly, and they may not readily provide the information required to define business processes. | Positive |
| **Team Members** | If the %time of time spent on the project by internal resources is low, then the speed required to define business processes will be low and this might impede business process clarity. Also sources of information required to define business processes might be sparsely produced. Also, if the incentives of the internal resources are low, they will be less likely to provide the relevant information and documentation required to define business processes. | Positive |
| **Process Owner Support** | If the sponsor strength is low, this will very likely impede on availability of process owners. In the event that this is the case, SME availability may be minimal. In the absence of SMEs and process owners, this will reduce the provision of information for business process definition. | Positive |
| **Organisational Readiness** | If the degree of buy-in from the business is low and the incentives for the project internal stakeholders are unattractive or non-existent, the stakeholders will be less likely to cooperate in clearly defining business processes. They will also be reluctant to provide the relevant documentation for business processes. | Positive |
| **External Readiness** | If the recognition of change by external stakeholders is low, they will be less likely to cooperate in clearly defining business processes. They will also be reluctant to provide the relevant documentation for business processes | Positive |

**Table 7-4:** Complexity Correlation Matrix

| Complexity Type / Complexity Type | Clarity of existing processes | Business process standardisation | Level of Experience | Onshore/Offshore/Rightshore | Total Team Size | Degree of Customisation | Customisation Factors | Interface Size | Integration of Legacy Systems | Quality of Data | Degree of Configuration | Hardware / Corporate Policies | Test Strategy | User Base | User Training Requirements | Trainer Attributes | Organisational Readiness | External Readiness | Leadership | Technical Scope | Team Attributes | Culture | Process Owner Support | Team Members | Module Maturity | Inter-Module Integration | Regulation | Exchange Rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clarity on Business Process | | 1 | -1 | -1 | | -1 | 1 | | | 1 | -1/1 | | | 1 | | | 1 | | | | | | -1 | | | -1 | | |
| Business Process Standardisation | | | -1 | | | -1 | -1 | -1 | -1 | -1 | -1 | | 1 | | -1 | | | | 1 | | | -1 | -1 | | | -1 | | |
| Level of Experience | 1 | 1 | | | | -1 | 1 | | | | -1 | | | | | | | | | 1 | | | | -1 | | -1 | | |

### 7.2.5 Phase 5 - Refinement

The developed complexities, uncertainty evaluation methods for the complexity data, complexity assessment approach for deriving a significance score, impact of classified complexities on WBS activities, and correlation of complexities were all refined. The refinement process involved the researcher presenting all these elements to the conceptual validation participants. Hence refinement was part of conceptual validation. The essence of the refinement process was to obtain an agreement on the complexity assessment framework. This activity was crucial in the development of C-REACT, and the process was iterative. The details of all the participants involved in the refinement process are provided in Section 5.3.1.4.

The conceptual validation participants were all satisfied and impressed with the complexity assessment framework as it is an indication of rigour in evaluating and costing complexity. On certain occasions, the meetings held with them were on an individual basis, and at other times, group workshops were held with the majority or all of the participants present. Most of the individual meetings lasted two hours and each of the workshops lasted two hours. The details of the meeting durations are presented in section 5.3.1.4.

#### 7.2.5.1 Refinement of Complexity Taxonomy

The researcher presented the developed complexities to the conceptual validation participants as discussed in Chapter 5. Several areas were discussed, some of which have been presented in Section 5.3.1.4.

**Suitability of Complexity Measurement**

Preliminary two-hour meetings were held individually with two IT complexity experts, Expert 26 from Company M and Expert 27, who is freelance. The essence of the meetings was to discuss the advantages of measuring and costing complexity using a semi-structured questionnaire and open-ended questioning. A separate two-hour meeting was also held with both participants together on this subject. Experts 26 and 27 advised that complexity is what drives project cost and the chances of success in the presence of complexity are minimal. Therefore a method is required in industry for measuring complexity and subsequently applying the measurement to cost analysis.

Expert 27 is also a Principal Enterprise Architect whose role focuses on information systems complexity. He was part of a group of three complexity experts who developed a complexity model for a bank in Germany. Expert 27 stated that although discussions on complexity are quite pervasive, there is limited research in this area. Additionally, Expert 27 cautioned that organisations are not yet ready for complexity management. Therefore, he asserted that the advent of C-REACT is at the right time and for the right reasons. He advised that C-REACT will measure and cost application complexity in an absolute manner. This allows an organisation to focus on one implementation at a time. He also emphasised that another reason for the suitability of C-REACT is because it allows organisations to budget more realistically for ERP implementations, and it creates a global awareness of complexity. Both Expert 26 and Expert 27 agree that C-REACT is suitable for complexity costing.

The process followed in obtaining the refined complexities as part of the conceptual validation was discussed in Chapter 5. The final taxonomy of complexities was ratified by all the participants presented in Chapter 5 who were involved in the conceptual validation of complexities. This process was fulfilled over an average of six two-hour individual meetings with each organisation, and two two-hour group workshops. The final taxonomy of complexities is the complexity breakdown structure (CBS) presented which is discussed later in this chapter as part of the framework. This definition followed an iterative process which started with the use of a questionnaire, as discussed in section 5.3.4.

### AS-IS/TO-BE Differentiation

In a two-hour meeting with the participants from Company C, they asserted that business processes should be standardised during implementation. They also emphasised that these processes should be part of a business case. Company C added that the effort in the complexity of standardising processes is the difference between AS-IS and TO-BE processes. AS-IS processes are current business processes, whilst the TO-BE processes are those defined for implementation in the future ERP solution. They advised that it is crucial to find the difference in complexity between AS-IS and TO-BE processes, in order to derive the cost of this difference. This will enable an organisation to ascertain whether or not they are implementing more standard processes than non-standard processes. Hence Company C proposed a new complexity type called AS-IS/TO-BE differentiation for the complexity dimension known as business process complexity.

### 7.2.5.2 Refinement of Uncertainty Method

The researcher presented the pedigree matrix for uncertainty assessment to the participants of the conceptual validation. Expert 17 from Company B did not support using the NUSAP technique for uncertainty assessment. His opinion was that NUSAP introduces an additional complexity to C-REACT. He advised that various organisations employ different methods in assessing and calculating uncertainty. However, he further suggested that the pedigree matrix may be better appreciated and utilised by ERP consultancies in their process of bidding for ERP implementation projects. This will enable the consultancies to demonstrate to their clients that they applied a structured methodology and rigour to uncertainty assessment. Company K (aerospace organisation), Company C (ERP implementation consultancy), Company I (risk analysis consultancy), and Company J (ERP implementation consultancy), were all in support of using the pedigree criteria of the NUSAP matrix to assess the uncertainty of identified ERP complexities.

In refining the pedigree matrix, the researcher presented the pedigree matrix proposed by Erkoyuncu *et al.* (2014) to manage the innovative uncertainty framework for supporting contracting for product-service availability in manufacturing. The matrix is presented in Table 7-5.

**Table 7-5:** Uncertainty Assessment Pedigree Matrix (Adopted from Erkoyuncu et al., 2014)

| Uncertainty Level | Basis of Estimate | Rigour in Assessment | Level of Validation |
|---|---|---|---|
| **1** | Best possible data, large sample, use of historical field data, validated tools and independently verified data | Best practice in well-established discipline | Best available independent validation within domain, full coverage of models and processes |
| **3** | Small sample of historical data, parametric estimates, some experience in the area, internally verified data | Sufficiently experienced and benchmarked internal processes with consensus on results | Internally validated with sufficient coverage of models, processes and verified data. Limited independent validation. |
| **5** | Incomplete data, small sample, educated guesses, indirect approximate rule of thumb estimate | Limited experience of applied process with lack of consensus on results | Limited internal validation, no independent validation. |
| **7** | No experience in the area | No established assessment processes | No validation |

In addition to the pedigree matrix, Company B proposed that three other uncertainty assessment methods should be implemented in C-REACT:

- Manual scoring using the same numbers for scoring as the pedigree matrix, but without any criteria.
- Flat percentage method which allows the user to specify a percentage against each complexity dimension. This percentage is added to the complexity cost.

- Pre-defined percentage method which is specified by all the participating organisations in the conceptual validation of complexity and uncertainty assessment. This percentage is added to the complexity cost.

Companies K, C, I and J had their reservations about implementing four uncertainty assessment methods because: (1) the development of C-REACT was constrained by time, (2) they wanted the tool to be kept simple, and (3) they believed that too many options might confuse the user of the tool. Therefore, all participants eventually agreed to utilise the pedigree matrix and manual scoring techniques. However, they expressed an interest in implementing the pre-defined percentages and advised that these be applied as default percentages in the model. The pre-defined percentages which are implemented as contingences will be discussed in Chapter 8.

The participants also suggested that uncertainty costing should be applied as an additional action in the event that the level of the complexity being assessed is very high. However, Company C advised that there will always be a certain degree of uncertainty at the commencement of assessment. Hence it is practical to account for uncertainty at the beginning of the complexity assessment process.

It was suggested that validation of the manual scores should be implemented in C-REACT in order to avoid the user inputting inappropriate values. A range of 1 to 7 was proposed in order to ensure control over the scoring process. The range is defined as follows:

- 1 means very low uncertainty
- 3 means low to medium uncertainty
- 5 means medium uncertainty
- 7 means high uncertainty

Each score reflects the scale of uncertainty in the pedigree matrix, except that a single criteria (e.g., low) is used in the manual scoring. This provides a simple system for the user to apply in their uncertainty scoring, in the event that they find the pedigree matrix complex.

#### 7.2.5.3 Refinement of Complexity Assessment Method

The analytical hierarchy process technique was initially presented to the participant from Company B. The details of this participant are presented in Chapter 5. Although he suggested that the application of neural networks instead, eventually he was satisfied with using AHP. Thereafter, the technique was presented to the other validators individually in a one-hour meeting. AHP was demonstrated as the preferred approach for assessing the importance of complexity. The outcome of this process will be an input to the costing process. All the validators were satisfied with AHP.

In the process of reviewing the AHP approach for complexity assessment, the participants of the conceptual validation requested that the traditional ranks be adopted in C-REACT, with numbers ranging from 1-9 as illustrated later in this chapter. Each rank represents the level of significance for its relevant complexity. The range is described as follows:

- 1 means minimal importance
- 3 means somewhat greater importance
- 5 means strong importance
- 7 means very strong importance
- 9 means absolute importance

## 7.3 Complexity Assessment Framework

The framework enables the identification and assessment of the complexities encountered by project resources during an ERP implementation. It is applied in the needs identification stage of an ERP whole life cycle project. This framework represents the first phase of the overall framework, complexity of resource and assessment costing tool (C-REACT). Once these complexities are identified and assessed, C-REACT produces two reports which enable the adopting organisation to understand, anticipate, and prepare to control the complexities. Scenario analysis may be conducted using the framework by applying different scenarios for a better understanding of the complexities and their impact on the implementation cost. Adapting different scenarios also allows for an understanding of the impact of uncertainty on the complexity cost. The framework is composed of eight stages as illustrated in Figure 7-4.

### 7.3.1 Requirements Definition

This is the first stage of the framework. The initial requirements for a business application are identified and specified in this stage. An initial scoping exercise is conducted using a work breakdown structure (WBS) in order to enable complexity classification and resource base costing. This WBS highlights the activities which will be executed during an ERP implementation, and the resources allocated to these activities. It forms the platform for the cost estimation of the assessed and classified complexities for the allocated resources. Although the discussion of the system requirements definition is outside the scope of this research, the details of activity scheduling and resource allocation for complexity costing are presented in Chapter 8.

### 7.3.2 Complexity Identification

Complexity identification is the second stage of the complexity assessment framework. Expert judgment will be adopted in fulfilling this process which will also involve brainstorming just like the risk identification approach for ERP implementations. In this stage, a taxonomy of eleven dimensions is presented to the user for identification. However, only eight dimensions will be assessed at any one time, as proposed in the conceptual validation discussed in Section 5.3.1.4. This requirement was in line with one of the AHP requirements, which is not to compare more than seven factors simultaneously. However, the validators and researcher agreed to add one more factor in order to be conservative.

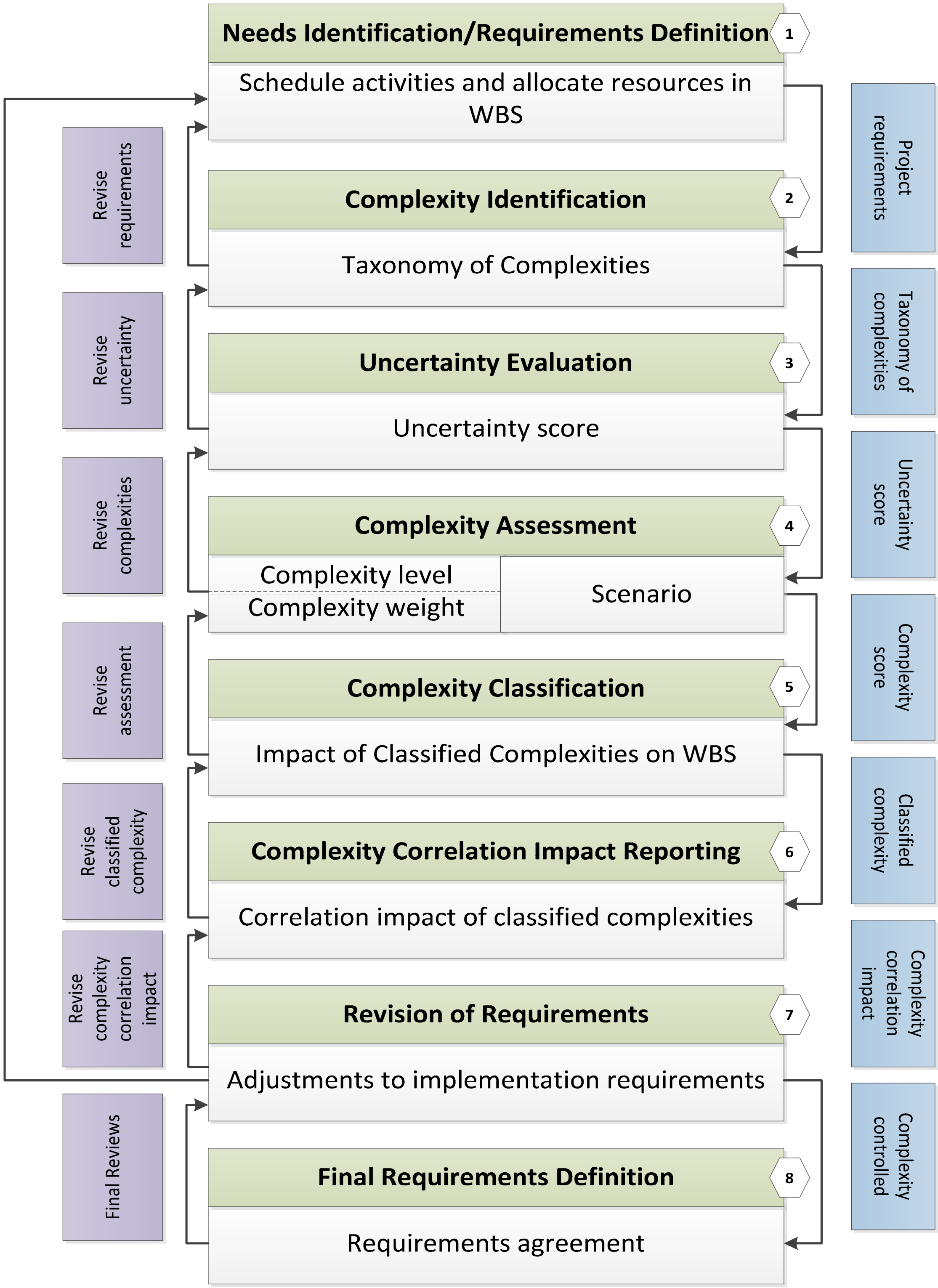



**Figure 7-4:** Complexity Assessment Framework

The first five dimensions are mandatory, and the last three dimensions are selected from the remaining six. The tool which embeds the framework prompts the user to select the remaining three complexity dimensions, as suggested by the conceptual validators. Some of the complexity dimensions in the taxonomy are business process complexity, customisation complexity, data cleansing and conversion complexity, and organisational readiness complexity. Figure 7-5 illustrates a screenshot of the complexity identification process. The complexity identification screen in C-REACT is presented as complexity dimension specification.

The user is prompted to select the dimensions which would be assessed for costing. In addition to this feature, the user may select the dimensions for which the uncertainty of the complexity would be assessed. This enables the user to evaluate complexity using different scenarios with and without uncertainty.

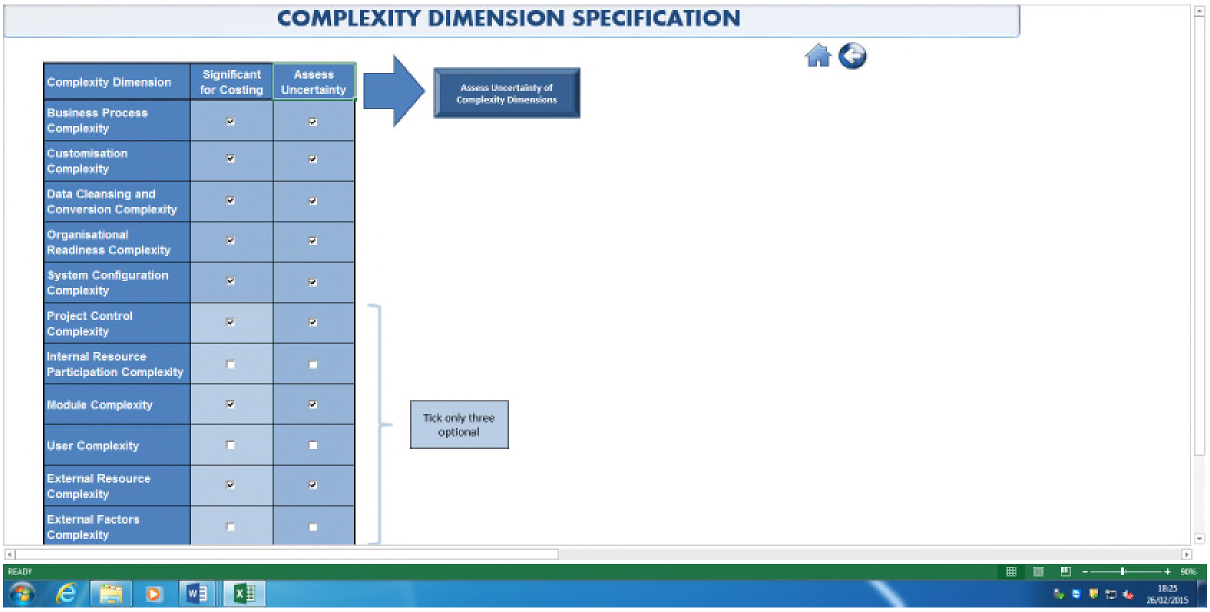


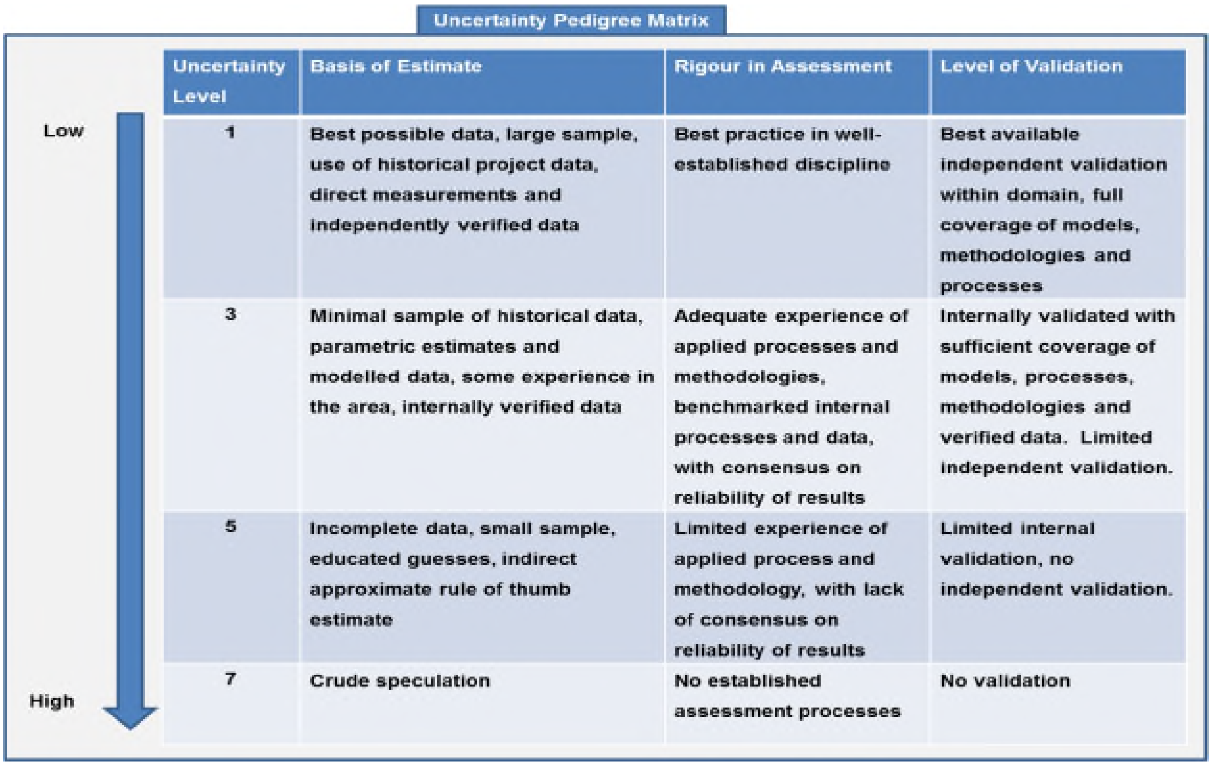

**Figure 7-5:** Screenshot of Complexity Identification Process in C-REACT

### 7.3.3 Uncertainty Evaluation

The business environment is characterised by high uncertainty; hence the process of ERP system assessment involves numerous problems. This difficulty necessitates uncertainty assessment for ERP complexities and challenges. This research assesses the uncertainty of the estimates for the eight identified ERP complexity dimensions through the use of a NUSAP pedigree matrix technique. This provides the user with a degree of confidence about the data provided for the complexities. This activity is fulfilled at the beginning of the complexity assessment process, following the complexity identification. The assessment process will be conducted by the potential ERP adopting organisation with the support of an expert. Two options will be displayed for the selection of a suitable assessment method: (1) NUSAP pedigree matrix; and (2) a manual scoring method.

The pedigree criteria employed in this research is illustrated in Figure 7-6. The criteria was adapted from Erkoyuncu *et al.* (2014), and comprises basis of estimate, rigor in assessment and level of validation. Erkoyuncu *et al.* (2014) describe the criteria as:

- Basis of estimate: typically refers to the degree to which direct observations are used to estimate the variable. The focus of this measure is the level of data that is available to be able to make a cost estimate.
- Rigour in assessment: refers specifically to the methods used to collect, improve, and analyse the data that is used to apply cost estimation.
- Level of validation: this metric refers to the degree to which efforts have been made to cross-check the data against independent sources.



Uncertainty Pedigree Matrix

| Uncertainty Level | Basis of Estimate | Rigour in Assessment | Level of Validation |
|---|---|---|---|
| 1 | Best possible data, large sample, use of historical project data, direct measurements and independently verified data | Best practice in well-established discipline | Best available independent validation within domain, full coverage of models, methodologies and processes |
| 3 | Minimal sample of historical data, parametric estimates and modelled data, some experience in the area, internally verified data | Adequate experience of applied processes and methodologies, benchmarked internal processes and data, with consensus on reliability of results | Internally validated with sufficient coverage of models, processes, methodologies and verified data. Limited independent validation. |
| 5 | Incomplete data, small sample, educated guesses, indirect approximate rule of thumb estimate | Limited experience of applied process and methodology, with lack of consensus on reliability of results | Limited internal validation, no independent validation. |
| 7 | Crude speculation | No established assessment processes | No validation |



**Figure 7-6:** Screenshot of Complexity Uncertainty Evaluation in C-REACT

It is illustrated in Figure 7-6 that uncertainty increases with the ranking. Each complexity dimension is ranked according to the pedigree criteria. For each dimension, an average score is obtained across all three ranks. This is known as the uncertainty score. A screenshot from C-REACT presenting the complexity dimensions against the pedigree criteria is depicted in Figure 7-7.

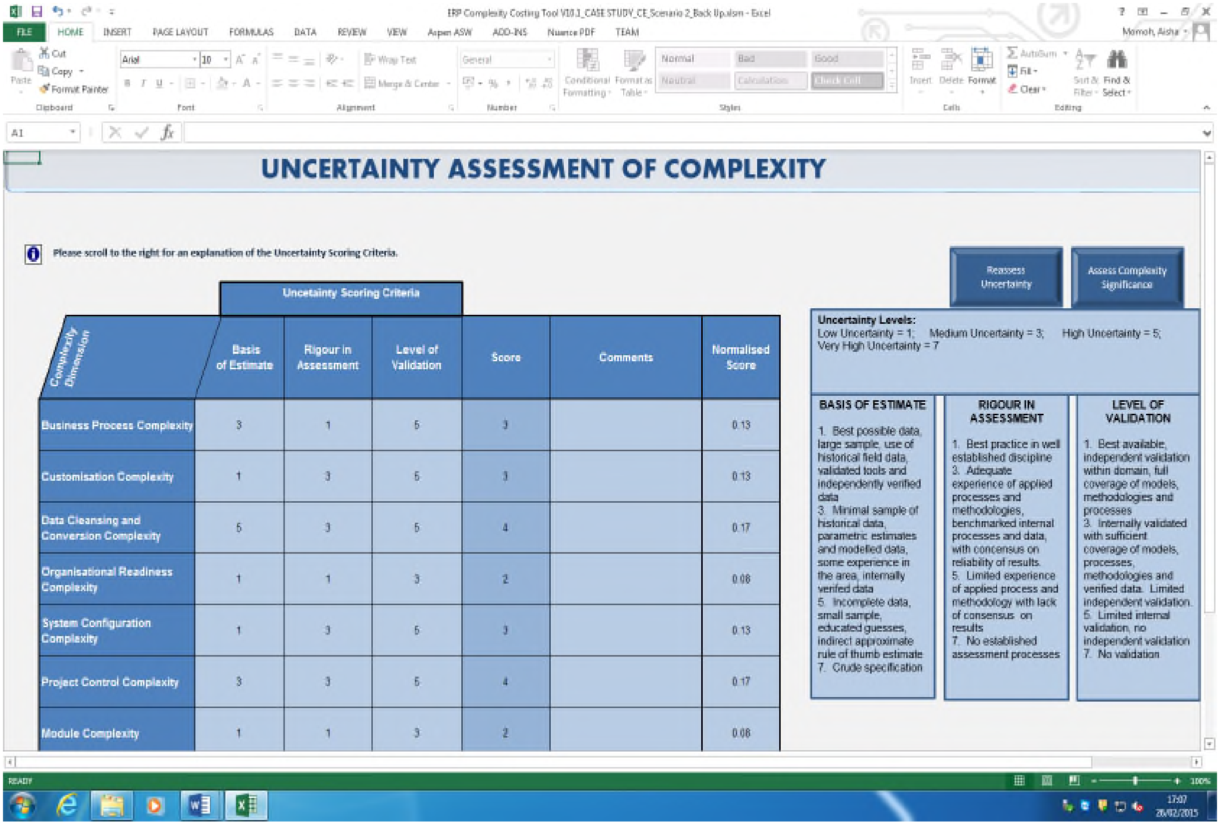



**Figure 7-7:** Screenshot of Uncertainty Assessment of Complexity Screen

The key ingriedient for the uncertainty assessment is data. An increase in the amount of available complexity data for cost estimating results a lower uncertainty. In the event that very little information is available, the uncertainty increases. The uncertainty score is used in the complexity costing process where it varies the complexity cost. The resource complexity cost estimation process with uncertainty is described in Chapter 8. A low uncertainty increases the confidence level of the potential ERP adopting organisation. This means that to attain a low uncertainty, the validation process of the complexity estimate must be thorough with sufficient information. In Figure 7-8, the relationship between complexity data for estimating, uncertainty assessment and complexity cost is exemplified.

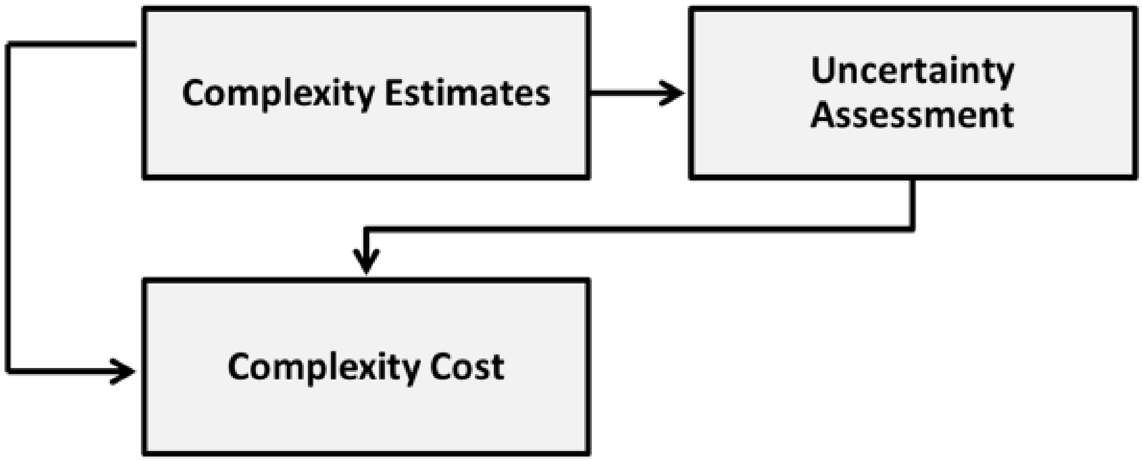



**Figure 7-8:** The Link between Uncertainty, Complexity Estimates and Complexity Cost

### 7.3.4 Complexity Assessment

The fourth stage in the framework is complexity assessment. This stage enables three processes: (1) the assessment of the importance of the identified complexities in relation to complexity cost; (2) selection of a suitable scenario for costing; and (3) the specification of the level of complexity for each complexity type. The first process derives a weight for each complexity, and the third process produces a complexity level.

#### 7.3.4.1 Complexity Weight

This step involves the production of a weight for each complexity dimension and type which are implemented in C-REACT using a complexity breakdown structure (CBS). The weight is derived by applying the analytical hierarchy process (AHP) technique. Wei *et al*., (2005) and Subramanian and Ramanathan (2012) propose four steps in the multi-attribute evaluation of AHP as depicted in Figure 7-9.


**Figure 7-9:** Phases for Application of AHP

The decomposition phase entails the project team developing the AHP hierarchy. The hierarchy will consist of a goal at the top and criteria and alternatives of choice at the bottom. As an individual cannot simultaneously compare more than seven objectives, it is suggested that the number of alternatives should be reasonably small, preferably seven in number (Bahurmoz, 2006). In the second phase, each decision maker utilises paired comparisons for the attributes and alternatives to extract judgment matrices. These paired comparisons are ranked using a nine-point scale at each level. The nine-point scale used in C-REACT is highlighted in Table 7-6. The third phase involves the repetition of the paired comparison process for each attribute in the alternative prioritisation problem to compute local weights. The fourth step involves the aggregating the weights to obtain the importance of attributes and the global priority of alternatives.

**Table 7-6:** AHP Scale of Relative Importance

| Scale | Numerical Rating | Reciprocal |
|---|---|---|
| **Minimal Importance** | 1 | 1 |
| **Somewhat greater importance** | 3 | 0.33 |
| **Strong importance** | 5 | 0.2 |
| **Very strong importance** | 7 | 0.14 |
| **Absolute (highest possible) importance** | 9 | 0.11 |

It is customary to use odd numbers from the nine-point scale in order to ensure a reasonable distinction among the measurement points. Even numbers may be used as well, but only in the case of negotiations in order to reach a compromise. For the purposes of this research, even numbers are not used. The rationale behind this decision is to enable estimators reach a concrete agreement on the importance of the complexities. Allowing intermediate values may introduce complacency and frivolity. The priority of comparison is prevalent in the criteria in row headings over those in the column headings. The algorithm for this comparison is illustrated in Figure 7-10. This algorithm was developed for computing the ranks of the complexity dimensions and complexity types, where $X_1$ represents the first complexity and $X_2$ represents the second complexity. Table 7-7 presents the complexity dimension prioritisation and comparisons, and Figure 7-11 presents a screenshot example of the comparison of complexity types using the AHP technique from C-REACT. Criteria with equal significance will have a ranking of 1. For instance, if business process complexity is compared against business process complexity, the ranking will be 1. In the event that an alternative is more important (for instance, 5 time more important) than another alternative, the latter will have the inverse value (0.2) of the former.

The user is enabled to input ranks against the complexities on the right-handside of the cells filled with the value '1' in the matrix. The left-handside of the cells with the value '1' is automatically calculated by the AHP algorithm as illustrated in Table 7-7.

The algorithm adopts the following logic:

- If the first criteria is equal to the second alternative, the value in the cell which they share is '1' – this value is automatically determined by the tool; hence the user is not required to make any such entries
- If the second criteria is greater than zero, then the first alternative will be assigned the inverse value of the second alternative.

- If the second criteria is less than zero, then the first alternative will be assigned the value in the denominator of the first alternative.

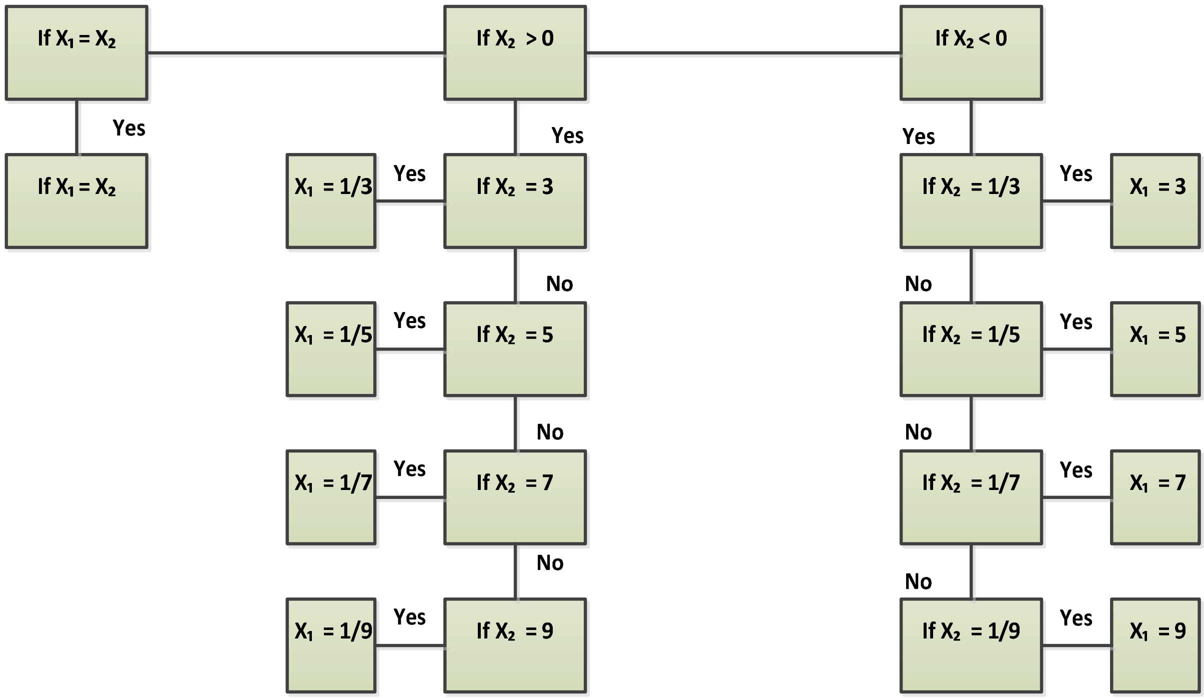



**Figure 7-10:** Algorithm for Complexity Ranking in AHP Matrix

The hierarchy for the complexity AHP matrix is based on the two levels in the complexity breakdown structure; the complexity dimension level and the complexity type level in relation to their importance in the context of costing. The complexity dimensions are compared against each other as indicated in Table 7-7. Thereafter, a weight is derived for each dimension. The weight for each of the complexity types is multiplied by the weight of the business process complexity dimension.

**Table 7-7:** Screenshot of Complexity Dimension Pairwise Comparison

| Complexity Dimension | Business Process Complexity | Customisation Complexity | Data Cleansing and Conversion Complexity | Organisational Readiness Complexity | System Configuration Complexity | Project Control Complexity | Module Complexity | External Resource Complexity | Weight |
|---|---|---|---|---|---|---|---|---|---|
| **Business Process Complexity** | 1.00 | 5.00 | 1.00 | 3.00 | 5.00 | 5.00 | 7.00 | 7.00 | 0.28 |
| **Customisation Complexity** | 0.20 | 1.00 | 0.11 | 0.33 | 1.00 | 0.33 | 0.33 | 1.00 | 0.04 |
| **Data Cleansing and Conversion Complexity** | 1.00 | 9.00 | 1.00 | 3.00 | 3.00 | 7.00 | 7.00 | 7.00 | 0.29 |
| **Organisational Readiness Complexity** | 0.33 | 3.00 | 0.33 | 1.00 | 5.00 | 5.00 | 5.00 | 7.00 | 0.17 |
| **System Configuration Complexity** | 0.20 | 1.00 | 0.33 | 0.20 | 1.00 | 3.00 | 1.00 | 5.00 | 0.08 |
| **Project Control Complexity** | 0.20 | 3.00 | 0.14 | 0.20 | 0.33 | 1.00 | 3.00 | 1.00 | 0.06 |
| **Module Complexity** | 0.14 | 3.00 | 0.14 | 0.20 | 1.00 | 0.33 | 1.00 | 3.00 | 0.05 |
| **External Resource Complexity** | 0.14 | 1.00 | 0.14 | 0.14 | 0.20 | 1.00 | 1.00 | 1.00 | 0.03 |

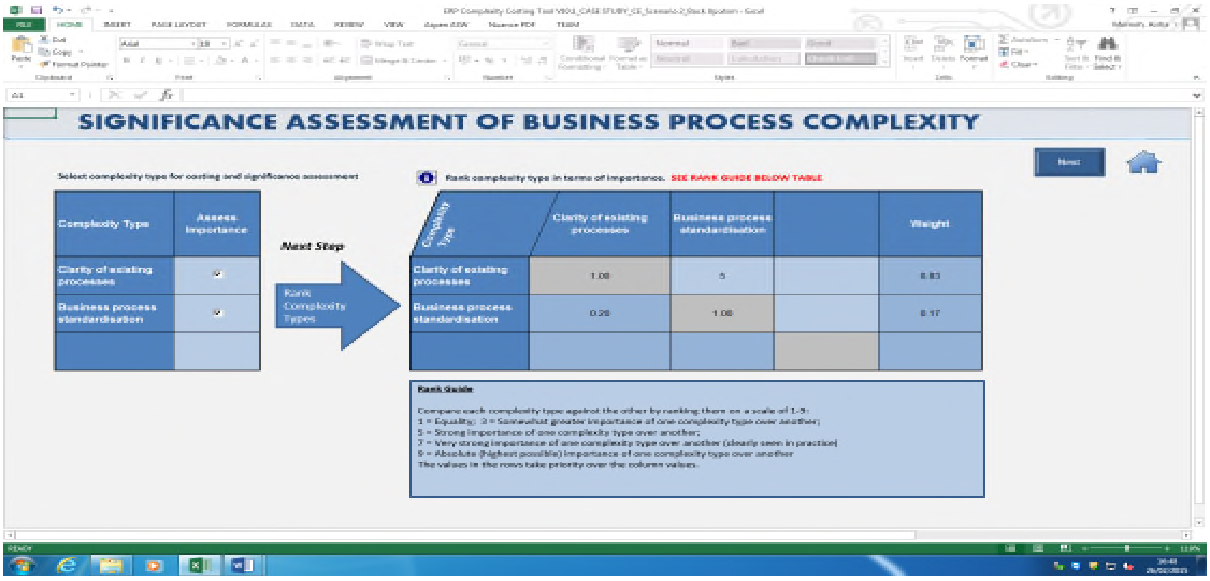



**Figure 7-11:** Screenshot of Complexity Type Assessment for Business Process Complexity Dimension

### 7.3.4.2 Complexity Level

The user of C-REACT is expected to select a scenario prior to specifying a complexity level which is the fourth part of the complexity assessment stage. Three scenarios are presented to the user as illustrated in Figure 7-12.

C-REACT is automated to produce the relevant values according to the specified scenario. The user would not need to specify complexity levels, as these are pre-specified. The complexity level is used in the complexity cost estimating process. The level determination commences with a scoring process. Each complexity dimension, type and cost driver is scored according to pre-defined complexity criteria, which was produced and ratified by all the collaborating organisations that participated in conceptual validation. The criteria was defined at the cost driver level. The initial scoring process is depicted in Figure 7-13.

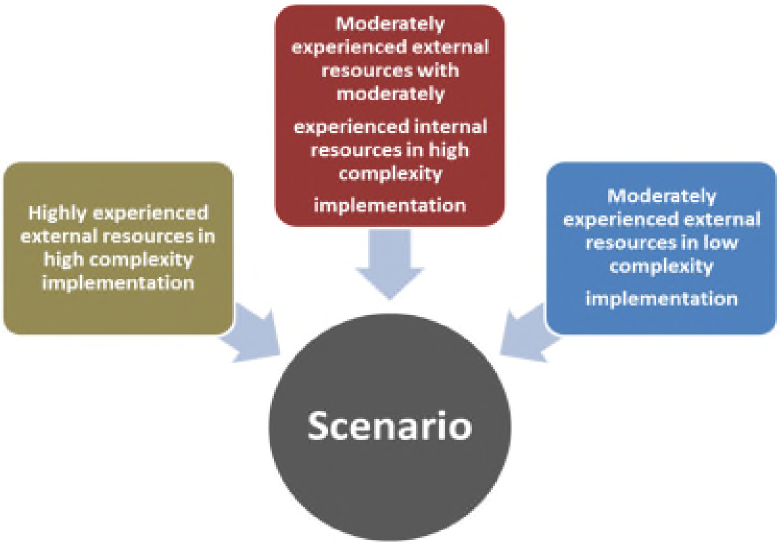



**Figure 7-12:** Complexity Assessment Scenario

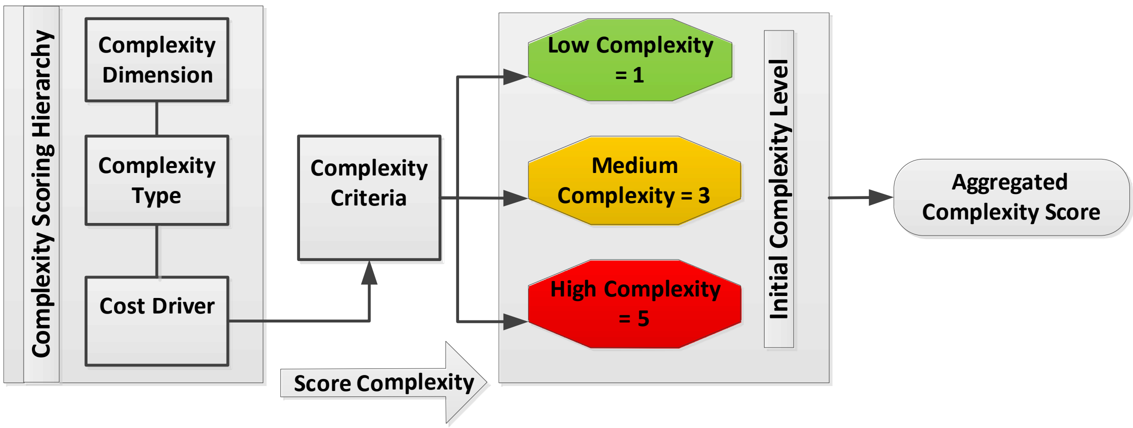



**Figure 7-13:** Initial Complexity Scoring Process

Each cost driver is assigned a set of three criteria, with each one scored as either 1 for low complexity, 3 for medium complexity or 5 for high complexity. This initial scoring is known as the initial complexity level. A subset of the scoring criteria as defined by the industrial collaborators in this research is presented in Table 7-8. Subsequent to discerning the initial complexity level, all the scores for the set of cost drivers for each complexity type are aggregated into one complexity level. This is performed automatically by obtaining an average across all the scores. The highest number obtained is 5. Therefore the final set of complexity levels range between 1 to 5 on a likert scale.

On the scale of 1 to 5; 1 means very low complexity, 2 is low complexity, 3 conveys medium complexity, 4 is high complexity, and 5 represents very high complexity. This range indicates the final complexity levels and applies to the complexity types.

**Table 7-8:** Complexity Scoring Criteria for Business Process Complexity

| Complexity Dimension | Complexity Type | Cost Driver | Low | Medium | High |
|---|---|---|---|---|---|
| **Business Process Complexity** | Clarity of existing processes | Roles | Compliant and audited | Clearly defined | Not clearly defined/a new role |
| | | Information | All sources clear | Some sources clear | Sources not clear |
| | | Definition | All processes clear | Some processes clear | Processes not clear/not global |
| | | Performance | All KPIs defined | Some KPIs defined | No KPIs defined |

### 7.3.5 Complexity Classification with WBS Complexity Matrix

The next step is to fulfil stage 5 of the framework where the complexities are classified by project activity. This is enabled with a WBS complexity matrix which correlates the complexity types with the project activities. The classification is accomplished by calculating a complexity number known as Kessington's complexity number (KCN). This process is illustrated in Figure 7-14.

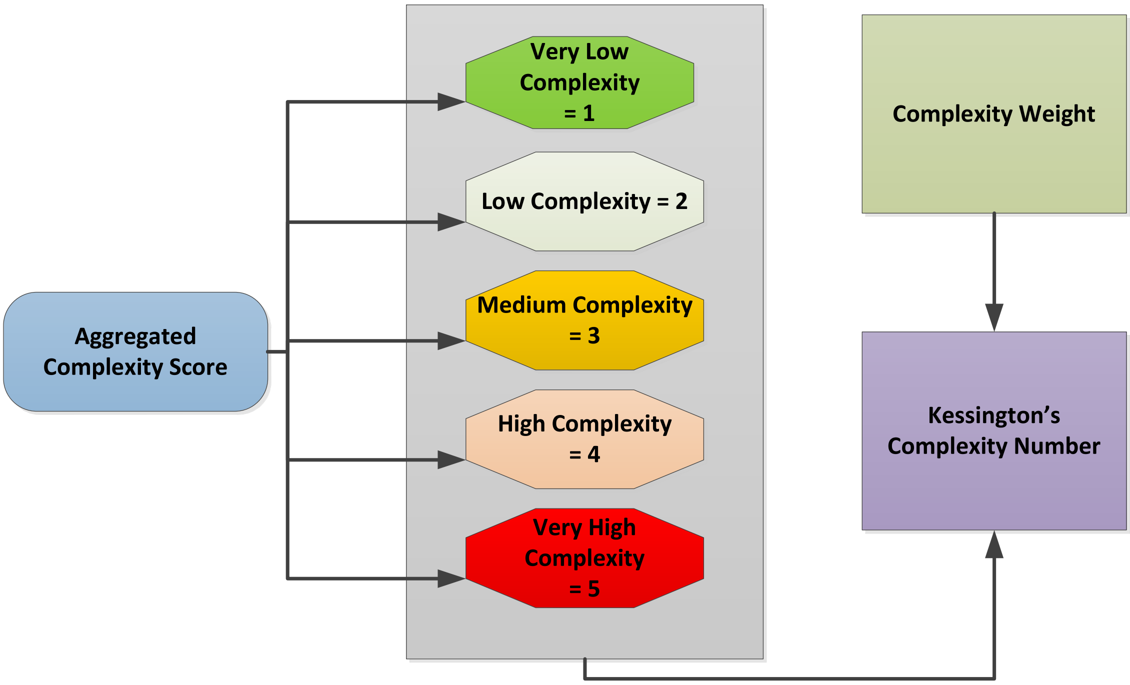
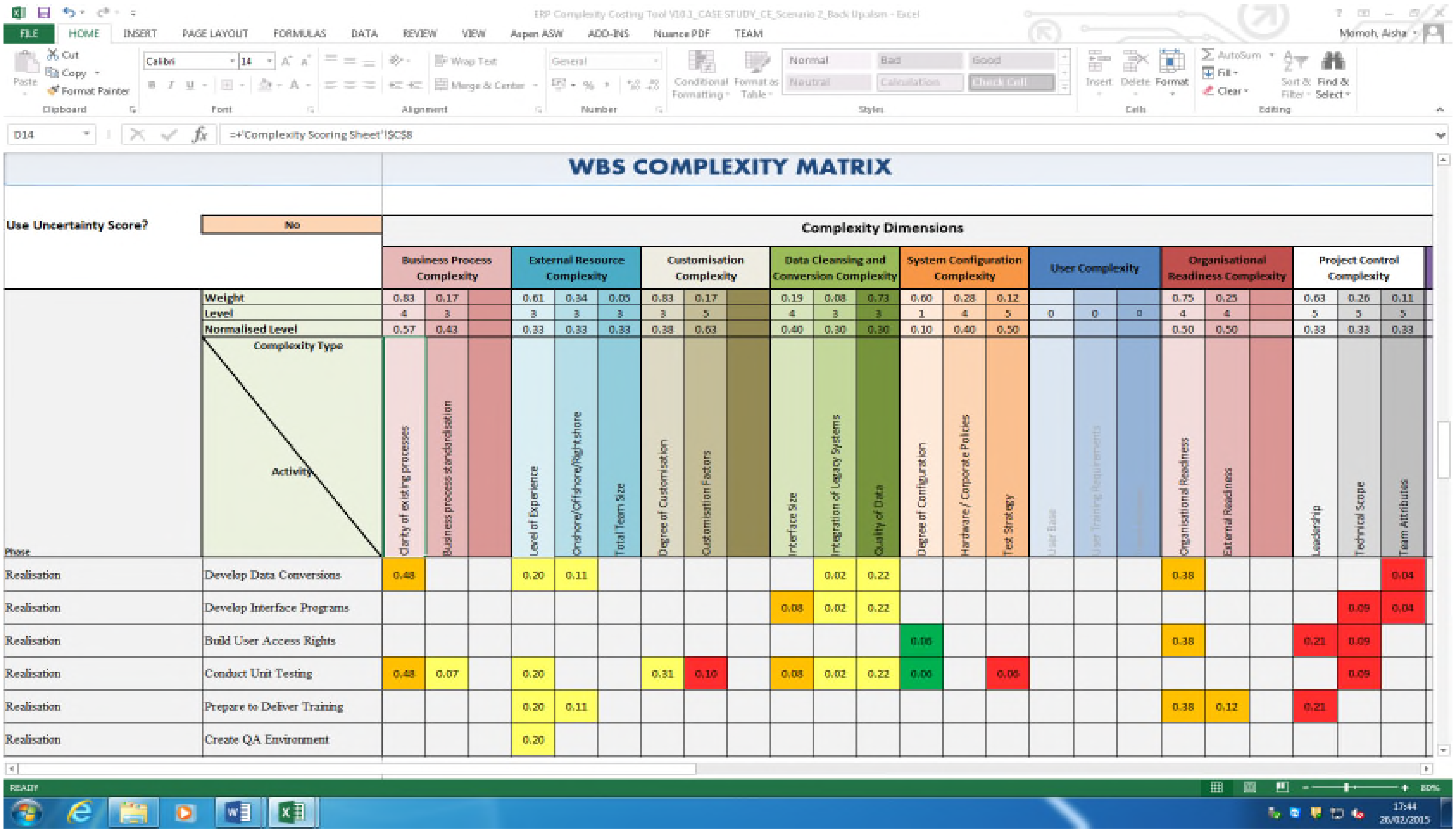



**Figure 7-14:** Final Complexity Score Derivation Process

Kessington's complexity number is a product of the normalised final complexity level and the weight which is obtained from assessing the significance of each complexity type. This number is used in the costing process, as will be discussed in Chapter 8. It is also used in the classification of the complexities according to the project activity as indicated in Table 7-15. The classification of complexity involves assigning the Kessington's complexity number for each complexity type to the activity in which the complexity is inherent. The cells which represent this mapping are flagged using colour coding in C-REACT.



WBS COMPLEXITY MATRIX

Use Uncertainty Score? No

Complexity Dimensions

| Phase | Activity | Business Process Complexity: Clarity of existing processes | Business Process Complexity: Business process standardisation | Business Process Complexity | External Resource Complexity: Level of Experience | External Resource Complexity: Onshore/Offshore/Rightshore | External Resource Complexity: Total Team Size | Customisation Complexity: Degree of Customisation | Customisation Complexity: Customisation Factors | Customisation Complexity | Data Cleansing and Conversion Complexity: Interface Size | Data Cleansing and Conversion Complexity: Integration of Legacy Systems | Data Cleansing and Conversion Complexity: Quality of Data |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weight | 0.83 | 0.17 | | 0.61 | 0.34 | 0.05 | 0.83 | 0.17 | | 0.19 | 0.08 | 0.73 |
| | Level | 4 | 3 | | 3 | 3 | 3 | 3 | 5 | | 4 | 3 | 3 |
| | Normalised Level | 0.57 | 0.43 | | 0.33 | 0.33 | 0.33 | 0.38 | 0.63 | | 0.40 | 0.30 | 0.30 |
| Phase | Complexity Type / Activity | | | | | | | | | | | | |
| Realisation | Develop Data Conversions | 0.48 | | | 0.20 | 0.11 | | | | | | 0.02 | 0.22 |
| Realisation | Develop Interface Programs | | | | | | | | | | 0.08 | 0.02 | 0.22 |
| Realisation | Build User Access Rights | | | | | | | | | | | | |
| Realisation | Conduct Unit Testing | 0.48 | 0.07 | | 0.20 | | | 0.31 | 0.10 | | 0.08 | 0.02 | 0.22 |
| Realisation | Prepare to Deliver Training | | | | 0.20 | 0.11 | | | | | | | |
| Realisation | Create QA Environment | | | | 0.20 | | | | | | | | |

| Phase | Activity | System Configuration Complexity: Degree of Configuration | System Configuration Complexity: Hardware / Corporate Policies | System Configuration Complexity: Test Strategy | User Complexity: User Base | User Complexity: User Training Requirements | User Complexity | Organisational Readiness Complexity: Organisational Readiness | Organisational Readiness Complexity: External Readiness | Organisational Readiness Complexity | Project Control Complexity: Leadership | Project Control Complexity: Technical Scope | Project Control Complexity: Team Attributes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weight | 0.60 | 0.28 | 0.12 | | | | 0.75 | 0.25 | | 0.63 | 0.26 | 0.11 |
| | Level | 1 | 4 | 5 | 0 | 0 | 0 | 4 | 4 | | 5 | 5 | 5 |
| | Normalised Level | 0.10 | 0.40 | 0.50 | | | | 0.50 | 0.50 | | 0.33 | 0.33 | 0.33 |
| Realisation | Develop Data Conversions | | | | | | | 0.38 | | | | | 0.04 |
| Realisation | Develop Interface Programs | | | | | | | | | | | 0.09 | 0.04 |
| Realisation | Build User Access Rights | 0.06 | | | | | | 0.38 | | | 0.21 | 0.09 | |
| Realisation | Conduct Unit Testing | 0.06 | | 0.06 | | | | | | | | 0.09 | |
| Realisation | Prepare to Deliver Training | | | | | | | 0.38 | 0.12 | | 0.21 | | |
| Realisation | Create QA Environment | | | | | | | | | | | | |

**Figure 7-15:** Screenshot of WBS Complexity Matrix

The colour changes between red through yellow and amber to green according to the level of complexity. The KCN falls between 0 and 1. The lower end of the complexity level presents a green light and changes to yellow as the number increases. The higher end of the complexity level displays a red colour in the relevant cell. The user is also presented with an uncertainty score prompt which allows the user to add uncertainty to the KCN should this be deemed necessary.

The classified complexities are displayed as a matrix as illustrated in Figure 7-15. This matrix is also a form of reporting which informs the user of the complexities arising, and the areas in the project which require attention according to their level of complexity. Most importantly, it is also used in complexity costing. This report enables the potential ERP adopting organisation to understand and prepare to control the complexities which they may encounter in the event that they implement ERP.

### 7.3.6 Complexity Correlation Impact Reporting

The complexity correlation impact reporting is the sixth stage of the framework. The correlation amongst all the complexities is reported in a complexity correlation matrix embedded in C-REACT. This matrix is presented in Figure 7-16, with an illustration of examples. The essence of the correlation report is to alert a potential ERP adopting organisation about the potential complexities which will emerge as a consequence of other complexities arising. This indicates to the organisation that the complexity cost is likely to rise beyond the estimated cost in the event that the initially reported complexities are not controlled. Each complexity is compared against every other complexity in a matrix by adopting the pairwise comparison technique, but without applying quantitative values. The correlation is reported in terms of positive and negative correlation. A positive correlation is a relationship between two complexities, where an increase in one correlates with an increase in the other, and vice versa.

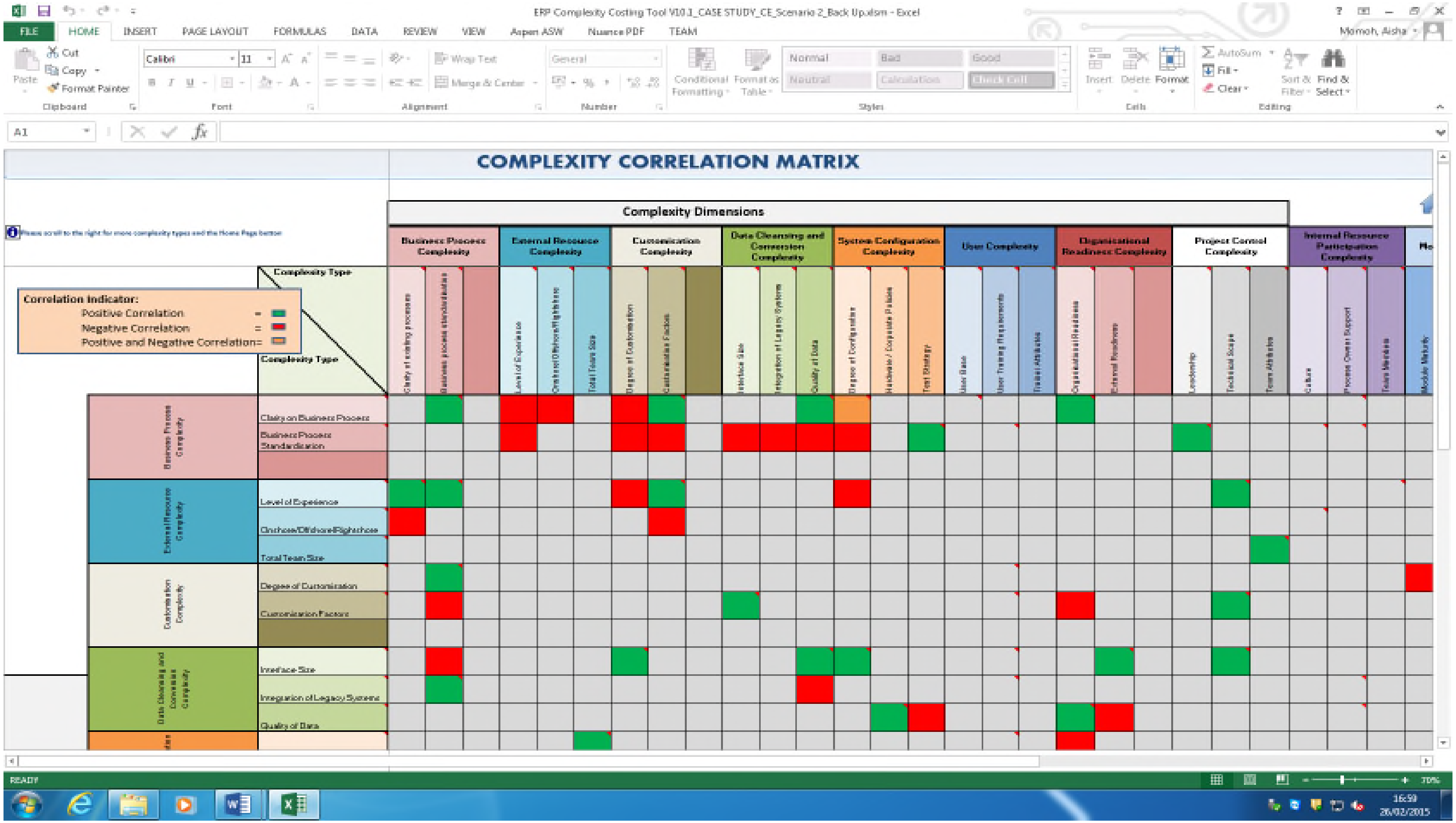



**Figure 7-16:** Screenshot of Complexity Correlation Matrix

An example of a positive correlation between the complexity types, clarity of business process and customisation factors is that in the event that business processes are not clear, the definition of customisation items will most likely not be clear either.

A negative correlation between two complexity types causes one of the complexity types to conduct the opposite of what the other one reflects. For instance, a correlation between clarity on business process and onshore/offshore/rightshore resources indicates that the less clarity there is on business processes will effect a higher proportion of required onshore resources. This correlation produces a red colour in the relevant cells of the matrix. A correlation that is both positive and negative produces amber in the matrix.

Each correlation is explained in the note for each complexity type that has a correlation with another in the complexity correlation matrix.

## 7.4 Summary

This chapter presents the ERP complexity assessment framework which is embedded in the complexity of resource and assessment costing tool. The chapter commences with the rationale behind proposing this framework, which is to enable potential ERP organisations to understand, assess and prepare to control complexity.

Section 7.2 highlighted the methodology which was adopted in defining the complexity assessment framework. The steps that were taken in obtaining the relevant information for the framework are: establishing a complexity breakdown structure for the identification of complexities, defining the NUSAP pedigree technique for the evaluation of uncertainty for complexity, selecting the AHP approach for assessment of complexities, using a work breakdown structure complexity matrix to classify complexity, applying a complexity correlation matrix for presenting the correlation amongst complexities, and refinement which is conducted for each of the previous phases.

Section 7.3 presented the ERP complexity assessment framework. The framework commenced with the identification of complexities, using a complexity breakdown structure consisting of all the developed taxonomies of complexity dimensions and complexity types. The next stage is the evaluation of the uncertainty for the information and estimates provided for the complexity. In this stage, the pedigree matrix is applied for assessing the uncertainty for each complexity. An uncertainty evaluation score is produced which will be used in complexity costing. The complexity assessment stage is subsequent and involves using the AHP technique to produce a significance weight for each complexity. Thereafter, a final complexity level is derived from scoring each complexity based on pre-defined criteria. Based on the product of the complexity level and the complexity weight, a Kessington's complexity number is produced for the assessed complexity types. This number classifies the relevant complexity types accordingly for each project activity in order to highlight the impact of each complexity in its relevant project activity. The next critical stage of the framework is complexity correlation impact reporting. In this stage, a matrix is presented to the user which constitutes the relationships amongst the complexities. This indicates the emergent complexities which are likely to arise as a consequence of the presence of other complexities.

# 8 COST ESTIMATION OF RESOURCE COMPLEXITY FRAMEWORK DEVELOPMENT

## 8.1 Introduction

This chapter follows on from the previous chapter where the complexity assessment framework was described. The framework is embedded in a tool known as Complexity of Resource and Assessment Costing Tool (C-REACT). In this chapter, the framework which represents the second phase of the overall framework for costing ERP resource complexity is presented. Some of its features have already been illustrated in the previous chapter. The complexity costing framework is also built into C-REACT. The essence of this framework is to enable the costing of complexities which have been identified and assessed for a potential ERP project. The cost of these complexities will be estimated according to the resources encountering the complexities. Therefore an early view of the potential project cost estimates will be obtained by an organisation contemplating an ERP solution. This cost can be used as the project estimate in an ERP project budget. It also enables an organisation to understand the areas of cost impact, and to prepare to control the costs by reducing the impacts. This chapter fulfils the research objective to design and develop a framework for the dynamic cost estimation of resource complexity to support in predicting potential ERP implementation cost. An outline of this chapter is presented in Figure 8-1.

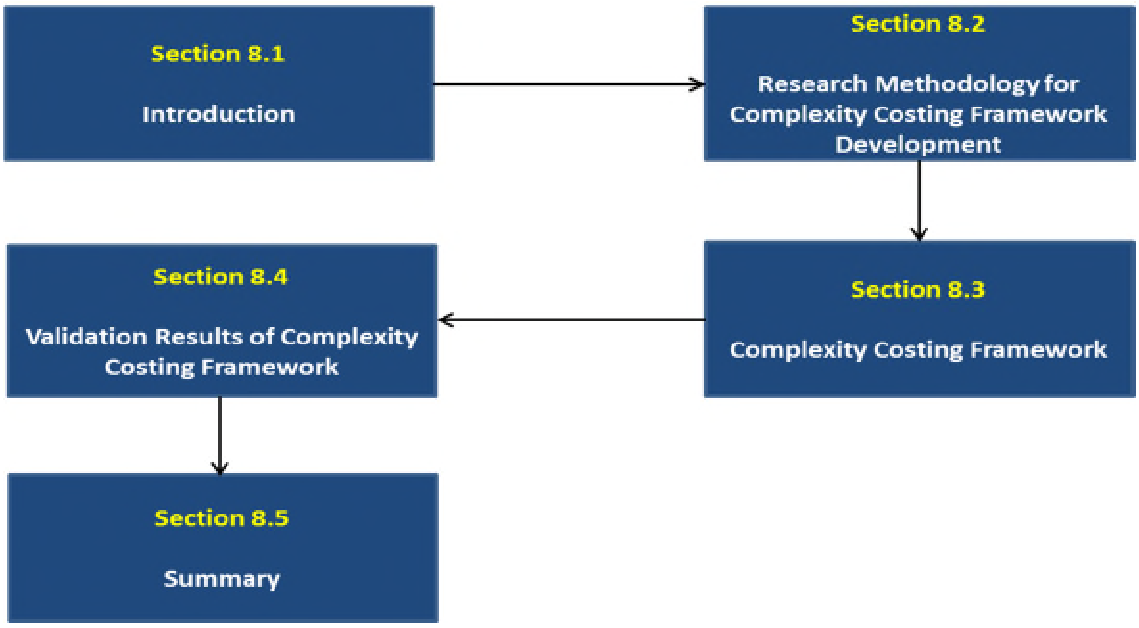



**Figure 8-1:** Outline of Chapter 8

## 8.2 Research Methodology for Complexity Costing Framework Development

A framework for estimating the cost of resource complexities was developed in this research. This framework is embedded in a tool called ERP Complexity of Resource and Assessment Costing Tool (C-REACT). The tool combines Microsoft Excel features with VBA programming and AnyLogic simulation. In order to enable the development of framework, a research methodology was defined. This methodology is illustrated in Figure 8-2.

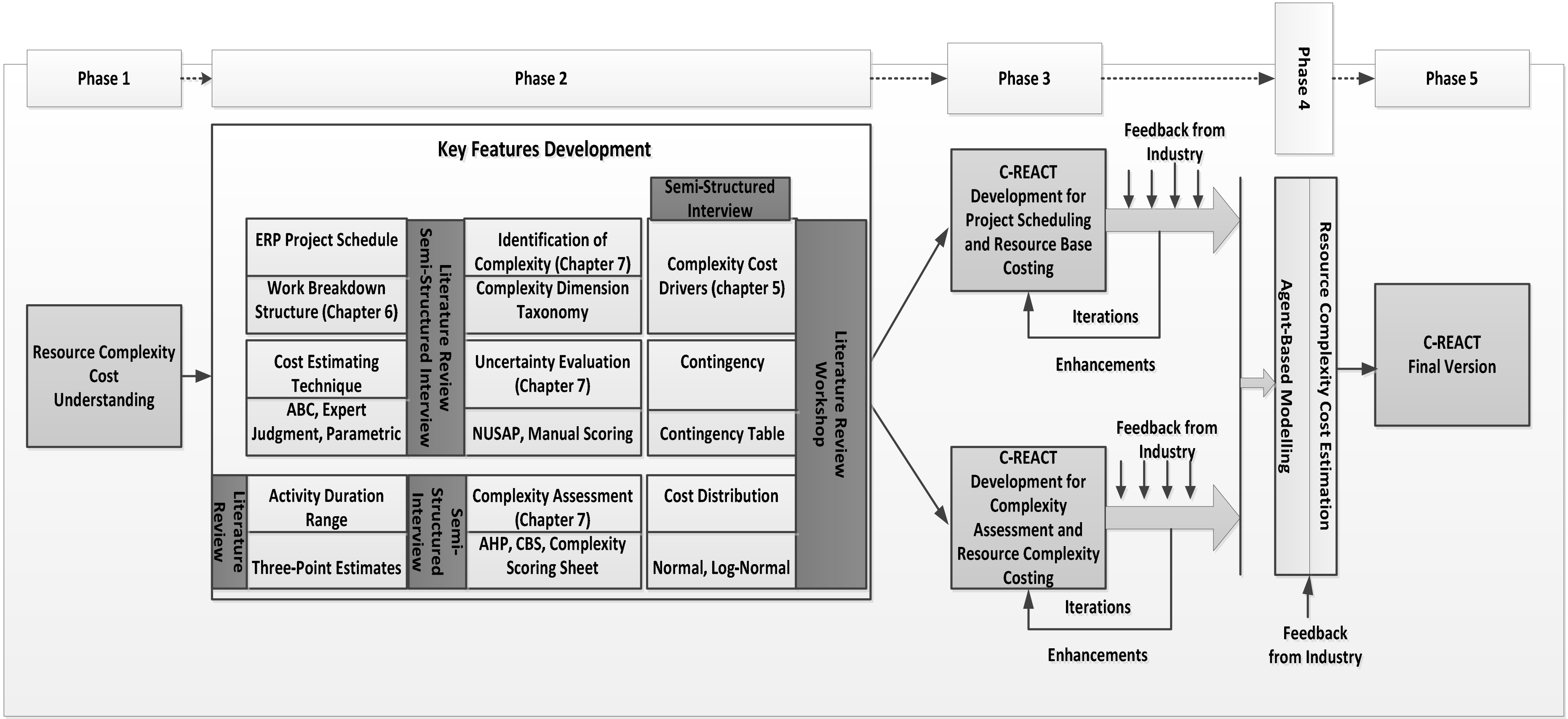



**Figure 8-2:** Research Methodology for Developing Complexity Cost Estimation Framework

The research methodology is composed of five phases:

- Phase 1 focuses on literature review, industrial collaboration, semi-structured interviews and the researcher's experience to gain an understanding of ERP complexity costing.
- Phase 2 defines all the key features required to develop the complexity costing framework
- Phase 3 entails the actual development of the framework and its refinement through conceptual validation. It entails two stages; (i) the development for project scheduling and resource base costing, and (ii) the development for resource complexity costing and cost simulation.
- Phase 4 establishes the process for the dynamic estimation of resource complexity costs through agent-based modelling
- Phase 5 focuses on the production of the final C-REACT version

In order to review the key features of the C-REACT development, three key questionnaires (one is presented in Appendix A), and two refinement questionnaires (one is presented in Appendix A) were defined. The refinement questionnaires were based on the results of the key questionnaires and were created in an effort to share the opinions of individual participants, with all the participants collectively for their feedback. Each of the three key questionnaires was individually presented in semi-structured interviews to six organisations and one IT complexity expert. The participants of the interviews are listed in Chapter 5.

Each interview lasted two hours, and was conducted with the participants from each organisation. The outcomes of these interviews led to group workshops and further individual meetings which entailed the refinement of the framework. Refinement sheets were used to facilitate these sessions (see Appendix A.3). The results of the conceptual validation and refinement are discussed in Section 8.4. The research methodology is described in detail in the following sections.

### 8.2.1 Understanding Resource Complexity Cost

This phase comprised of a detailed literature review in Chapter 2, the researcher's experience and current industrial practice discussed in Chapter 4. The essence of this phase was to gain an understanding of ERP complexities, complexity metrics, costing techniques, cost distribution techniques, cost simulation techniques, project activities and potential resources for each activity. The research methodology for development of the project activities and resources is presented in Chapter 6, and the methodology for development of complexities is discussed in Chapter 5.

### 8.2.2 Development of Project Schedule

This part of the research methodology entails the specification of the elements comprising the project schedule which would be embedded in C-REACT. A work breakdown structure (WBS) is used to present the project activities and resources. The WBS is presented in Chapter 6.

### 8.2.3 Selection of Cost Estimating Technique

Activity-based costing (ABC) was selected as the costing technique which will be applied in this research. This selection was based on the literature review which was conducted on cost estimation techniques in Chapter 2. The benefits of adopting ABC include support for cost estimation of new projects or ongoing projects, control of project execution in terms of cost and work accomplished, and performance evaluation of project manager and project team members responsible for various activities (Raj and Elnathan, 1999). The complexity assessment and costing of each resource which is produced in C-REACT will be used to accomplish the performance evaluation of project managers and project team members enabled through ABC. As the work breakdown structure (WBS) is a task-oriented structure, it would be well suited to serve as the basis for the ABC hierarchy. This WBS has been developed in Chapter 6 of this thesis. Detailed cost estimation is done from the bottom up, starting with estimates for each of the work packages and summarising the costs upwards through the structure up to its root, which is the element that presents the entire project.

In order to confirm the reliability of cost estimates, multiple costing techniques will be adopted. Therefore, a combination of expert judgment, ABC and a WBS will be used as the cost estimation approaches in this research.

### 8.2.4 Definition of Three-Point Estimates for Activity Duration

This part of the methodology involves defining a method for specifying the duration for each project activity. The duration is specified using a three-point estimate. Three-point estimating is introduced in order to account for the uncertainty in the duration. As defined in Section 2.9.1, a three-point estimate constitutes three possible durations for each activity as follows:

- Pessimistic duration which is the maximum number of days (or hours) for executing an activity
- Optimistic duration which is the minimum number of days (or hours) for executing an activity
- Most likely duration which is most likely number of days (or hours) it would take to complete the activity

The project evaluation review technique (PERT) formula which comprises of three-point estimating that is used to calculate the expected duration (T) applied in calculating the effort required for the activity is as follows:

$$T_E = (O + 4M + P) / 6 \qquad \textbf{(8-1)}$$

where P = pessimistic duration

M = most likely duration

O = optimistic duration

The expected duration (T) represents a triangular distribution. The three-point estimate is later used in the probability distribution of durations during the dynamic cost estimating described in Chapter 8 of this research. PERT was defined in Section 2.9.1.

### 8.2.5 Identification of Complexity and Uncertainty Evaluation

Identifying the complexities which would be embedded in C-REACT is a key part of the methodology. A complexity breakdown structure (CBS) is developed for application in C-REACT. This CBS is presented in Chapter 6 and discussed in Chapter 7. The technique which was selected for evaluating the uncertainty associated with complexity estimates is presented in Chapter 7. The two methods selected for evaluation are the NUSAP pedigree criteria and a manual scoring system.

### 8.2.6 Complexity Assessment

Complexity assessment enables the scoring and costing of complexity. The score obtained from the assessment is a complexity metric. The two methods selected for assessing complexity are analytical hierarchy processing (AHP) and complexity scoring using pre-defined criteria which are discussed in Chapter 7. The AHP derives a complexity weight and the complexity scoring produces a complexity level. The product of the complexity weight and complexity level is a final complexity level which is called Kessington's complexity number (KCN). This value is used in the complexity costing process.

### 8.2.7 Defining Cost Drivers for ERP Complexity Costing

In order to cost ERP resource complexity, cost drivers must be specified for this purpose. Therefore each complexity type is mapped to a set of cost drivers using a mindmap. The development process of these cost drivers is discussed in Chapter 5. Eighty-one cost drivers which are embedded in C-REACT were defined. Most of these cost drivers are qualitative in the sense that they are not directly measurable. Some of the cost drivers are quantitative, thereby enabling a direct measurement of complexity. However, all the cost drivers are measured using the criteria discussed in Chapter 7.

### 8.2.8 Defining Contingency

A contingency percentage table was defined by the industrial collaborators to enable the selection of a value which would be added to the resource complexity cost in the presence of a high complexity in a critical path activity. The contingency values represent five uncertainty percentages. Each percentage is driven by a range of uncertainty scores derived from the NUSAP pedigree matrix. This range determines the percentage that would be added to the resource complexity cost, depending on the uncertainty score associated with a complexity dimension. The application of contingencies in high complexity scenarios was suggested and agreed upon by the organisations that participated in the refinement for C-REACT. Additionally, all participants emphasised the importance of applying non-linear values to the percentages. This symbolises the fact that complexity may manifest in a project at any time, without a structure to predict the amount of complexity which may emerge.

### 8.2.9 Selecting a Cost Distribution

In order to establish a level of confidence with the estimates obtained from C-REACT, the researcher proposed the application of Monte Carlo to the participants of the conceptual validation. The essence of using Monte Carlo is to address the uncertainty in the cost estimates to produce an acceptable cost distribution. All the participants agreed to this suggestion. Normal distributions are often used in social sciences for random variables whose distributions are not unknown. However, the distributions are continuous and can take on a continuous range of values. This qualifies normal distributions as continuous probability distributions. According to Wikipaedia, the normal distribution applies the central limit theorem which states that under mild conditions, the mean of many random variables independently drawn from the same distribution is distributed normally, irrespective of the form of the original distribution. Also, many results can be derived analytically in explicit form when the relevant variables are normally distributed. Hence, this distribution suits the scenario of the cost estimates produced by C-REACT. In a normal distribution, the frequency with which certain returns occur, lie on a normal curve. The normal distribution calculates a mean and standard deviation; however, it is more applicable when the standard deviation is not too far away from the mean.

### 8.2.10 C-REACT Development with Industrial Feedback

The development of the complexity of resource and assessment costing tool (C-REACT) enables three key functions:

- Project scheduling and resource base costing which enables the specification of the relevant WBS elements for the estimating of resource base costs. This function is embedded in Microsoft Excel and developed using VBA.
- Complexity assessment and resource complexity costing which drives the process of uncertainty evaluation, complexity significance assessment and complexity scoring. These processes are described in the complexity assessment framework in Chapter 7 of this thesis. The outputs of this process derive a complexity measure for costing. Microsoft Excel and VBA are used to develop this function.
- Dynamic Resource Cost Estimation which simulates the resource complexity costs using agent-based modelling. This model is developed in AnyLogic.

AnyLogic was selected for this research because it is a simulation modelling software tool which enables the combination of three modelling techniques namely agent-based modelling, discrete event modelling and system dynamics within the same model. Therefore, it provides a platform for combining the ABM in C-REACT with other techniques for future research. Additionally, as the researcher commenced the framework development with an exploration of suitable techniques, AnyLogic seemed appropriate to utilise. Furthermore, it allows the model to be extended through java code, which is implemented in C-REACT.

The framework development was an iterative process which involved refinement and conceptual validation. The feedback and results obtained from the refinement and validation are provided in Section 8.4.

### 8.2.11 Dynamic Cost Estimation

The approach selected for estimating the resource complexity cost is agent-based modelling (ABM). This enables a dynamic cost estimation process through simulation. Although there are other simulation techniques like discrete event modelling and system dynamics, ABM fits the purpose of this research because it can be used to model people, organisations or projects as agents. As this research focuses on the costing of complexities encountered by project resources, they can be modelled as agents. Additionally, agents in ABM are characterised by; (1) emergence which enables the evolution of complexities, and their non-linear and exponential impact on cost to be modelled in ABM, (2) learning and adaptability which would aid each project resource to learn about the activities to which they are allocated, distinguish between parallel and sequential activities, execute the correct activity at the right time, identify their complexities through their activities, and calculate only the complexity costs they have incurred (3) interaction which would enable the resources to communicate with each other in terms of commencement and completion of activity to avoid collision, and (4) what-if scenario analysis capability which would allow the stakeholdes to make well-informed decisions based on cost estimates on different complexity scenarios. Therefore, the ABM technique employed in this research models the cost estimation of resources. The resources are presented as agents.

## 8.3 Cost Estimation of Resource Complexity Framework

The complexity costing framework enables the costing of the complexities encountered by ERP resources, whom are both internal and external project team members. It provides an organisation with a view of the resources experiencing the complexities and the cost of each resource to the organisation. Therefore, the estimated project cost can be managed and reduced by controlling resource complexity, which is outside the scope of this project. The framework is presented in Figure 8-3.

The framework is composed of the following seven steps:

1. Definition of work breakdown structure
2. Complexity identification and assessment-
3. Map complexity type to cost driver
4. Dynamic resource complexity cost estimating
5. Contingency specification
6. Monte Carlo simulation
7. Revise project requirements

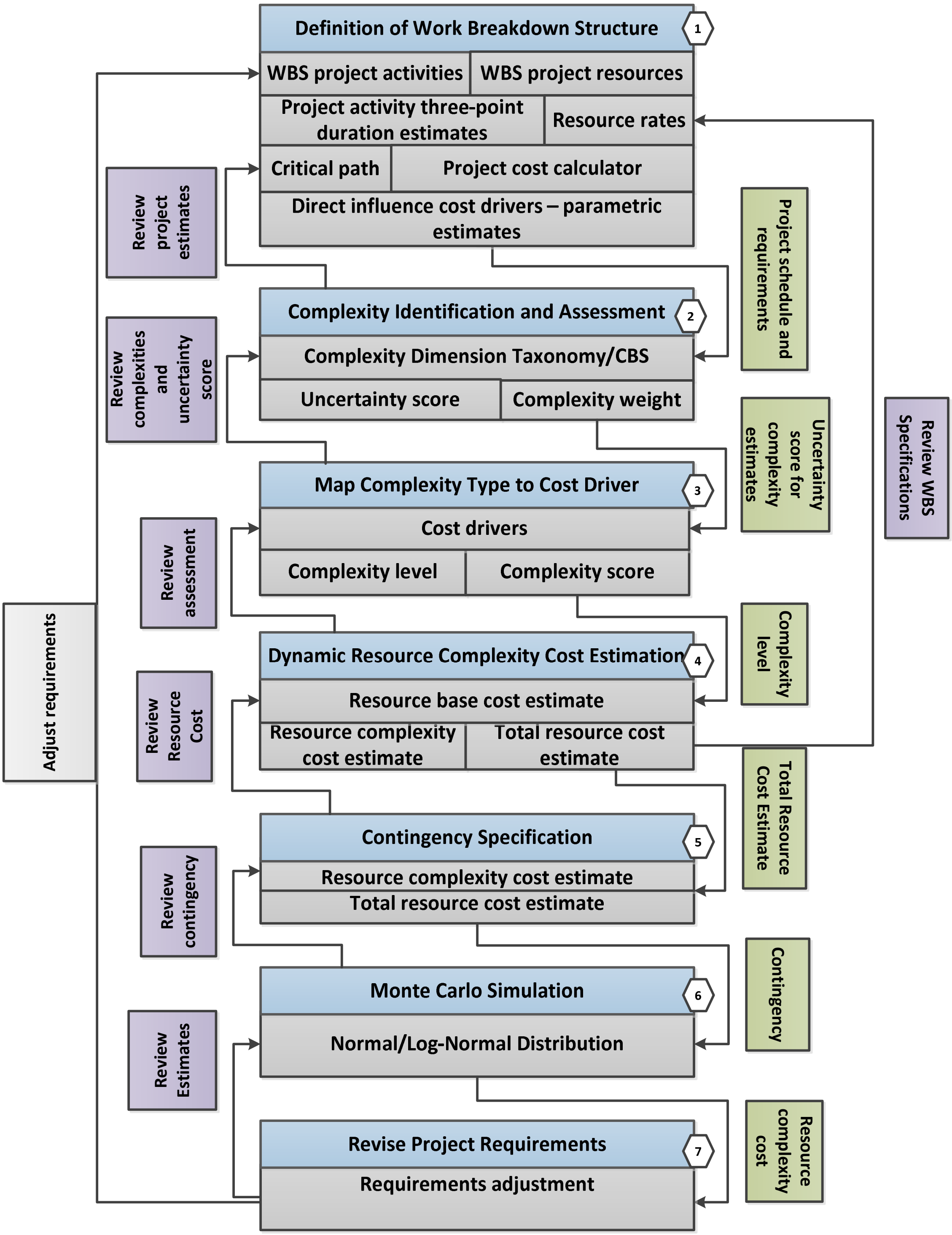



**Figure 8-3:** Cost Estimation of Resource Complexity Framework

### 8.3.1 Definition of Work Breakdown Structure

This stage is a subcategory of the system requirements definition stage which is introduced in Chapter 7. In this stage, the work breakdown structure embedded in C-REACT is used to identify the project activities which will be executed in the project. Secondly, resources are allocated to these activities. A rate should be agreed with each resource, which will be specified in order to calculate the cost of each resource. Fourthly, a three-point estimate is applied in specifying the duration of each activity. The most likely estimate is specified by the user. Consequently, the tool automatically calculates a default range for the optimistic and pessimistic estimates. This range is a +20% for the pessimistic duration and -20% for the optimistic duration. The range was proposed by Company J, an ERP implementation consultancy. All other participants involved in the conceptual validation concurred with this suggestion. The details of these participants are provided in Chapter 5. A range allows for uncertainty to be accounted for in the activity durations as very little information will be available at the time of the estimation. However, in the event that the essence of the potential project is to add new functionality to an already existing ERP solution, sufficient information may be available. Irrespective of the level of information, the full scope of the project would be unknown. The range caters for the fact that complexities and risks are inherent in ERP implementations. The user is also permitted to change the rate as they deem necessary. The project evaluation review technique (PERT) equation 8-1 is applied to the three-point estimate to establish the final duration for each activity. PERT is applied to project activities with very high uncertainty, especially in the absence of the relevant data. This is discussed in Section 2.9.1.

The tool has the capability to enable the specification of a critical path for each activity. Later on in the framework, in the event that an assessed complexity is high, it is checked against a critical path. Should it be in a critical path, an amount of contingency is added to the complexity cost.

Once the relevant elements in the WBS have been filled, the user may choose to calculate the preliminary project cost. A dynamic cost calculator is provided for this purpose. It provides the cost of each activity, each resource and a subtotal for each phase. A total project cost is also calculated. These costs do not include assessed complexities. The final cost estimate is based on assessed complexities and the resources encountering these complexities.

Each project activity produces deliverables which contribute to its cost. Therefore, cost drivers have been defined to enable activity costing through parametric estimating. These cost drivers are described as direct influence because they have a direct impact on specific line items in the work breakdown structure. The line items are the project activities. Tasks are created in the relevant activities to cater for the elements which are converted to cost drivers in the event that they are measurable. This property of measurability classifies the cost drivers as quantitative. The cost drivers are outlined in Appendix B.2.

Parametric estimating for the quantitative cost drivers is accomplished by defining a rate and quantity for each cost driver. This rate and quantity are used as the basis for the estimation as defined in the following equation:

$$m = x / n \qquad \textbf{(8-2)}$$

where $n$ = number of items in activity per day
$x$ = current number of items in activity
$m$ = most likely duration

The value which is derived for the most likely duration is used to automatically update the most likely duration part of the three-point estimate for the activities impacted by these cost drivers in the WBS. The rates are pre-defined by the industrial collaborators of this research, and are used as the default values in C-REACT. The potential number of items per activity varies according to project and is manually specified in C-REACT by the user.

### 8.3.2 Complexity Identification and Assessment

The complexity identification and assessment process is discussed in Chapter 7. The identification of complexity dimensions is conducted by using a complexity taxonomy. Once the complexity dimensions have been identified, the uncertainty for the complexity estimates is determined by generating a score. Thereafter, a pairwise comparison is performed for the complexity dimensions and types to assess their significance. In order to link complexity dimensions with their associated types, a complexity breakdown structure (CBS) is used for this purpose. The output of the comparison is a weight which is calculated for each complexity dimension and type.

### 8.3.3 Map Complexity Type to Cost Driver

In order to cost the complexities inherent in an ERP implementation, complexity measures are established for the relevant complexities. These measures are the cost drivers which are linked to complexity types, as illustrated in Chapter 5. Each driver is used to determine a complexity level by selecting a complexity criteria in the complexity scoring process. This process is part of the complexity assessment framework which is presented in Chapter 7.

To define a complexity level for each complexity type, the user selects a complexity criteria through the associated cost drivers. The complexity level is multiplied by the complexity weight to produce a complexity number. This complexity number is known as Kessington’s complexity number (KCN) which is applied to a resource base cost later on in the framework, to obtain a complexity cost.

### 8.3.4 Dynamic Resource Complexity Cost Estimation

The calculation of the base cost, complexity cost and total cost estimates for the resources involved in the WBS project activities are simulated in this stage of the framework. AnyLogic is the tool which is used in simulating the cost estimates. This estimation process is executed after the complexities have been identified and assessed in C-REACT. The simulation technique which is adopted for dynamic resource complexity costing is agent based modelling (ABM) which represents a model of the world as agents. In the context of this research, the agents emulate the project resources who have been assigned to activities in the WBS which is embedded in C-REACT. The resource cost estimation process is demonstrated in Figure 8-4. The process constitutes four steps.

In the first step of the process, the simulation process is executed for each active resource in the WBS. For each resource, the activity within which he or she is working at the time of simulation is obtained as an input into the costing process. Additionally, the three-point estimates for the duration of the activity, and the resource rates are inputs to this estimation process. The simulation generates a triangular distribution for the three-point estimates and converts these values into a single-point estimate. The resource daily rate and number of resources in the relevant activities are also obtained. These data are used to calculate the resource base cost.

The second step of the process entails the calculation of the resource base cost estimate. This estimate uses the resource cost data obtained in step 1. The resource base cost is calculated in Equation 8-3.

$$Ci = Qi * Ei * Ri \qquad \textbf{(8-3)}$$

where C = Cost, Q = Resource Quantity, E = Resource Effort, R = Resource Rate, i = Agent

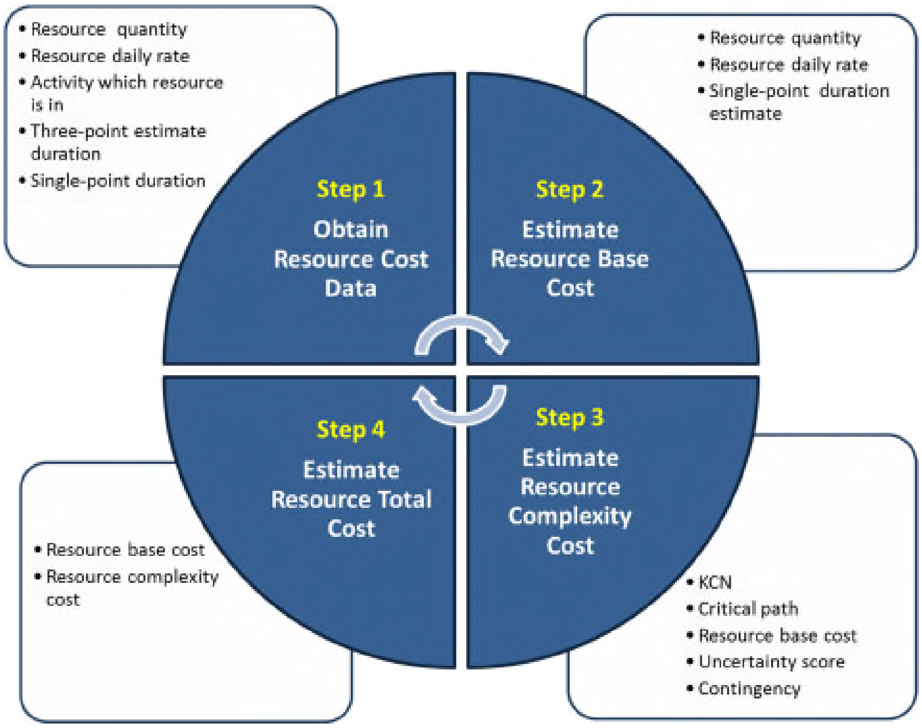



**Figure 8-4:** Resource Complexity Cost Estimation Process

The resource base cost is applied as an input to step 3 of the process. Other key inputs are the Kessington's complexity number (KCN), the flag for each relevant activity in a critical path, the uncertainty score, and contingency percentage. In calculating the resource complexity cost, the KCN is treated as a percentage. The resource complexity cost is calculated in Equation 8-4.

$$c = (n * b) + g \qquad \textbf{(8-4)}$$

where c = resource complexity cost

n = Kessington's complexity number

b = resource base cost

g = contingency

The contingency is only added the resource complexity cost if it contains a value. The contingency is obtained in the event that the level of the complexity which has been assessed for cost estimating is high and is in a critical path activity. In the absence of this condition, there is no contingency applied to the resource complexity cost.

Step 4 of the process accepts both the resource base cost and the resource complexity cost, and adds both figures in Equation 8-5. The result of this calculation is the resource total cost with complexity.

$$e = b + c \qquad \textbf{(8-5)}$$

where e = resource total cost estimate

b = resource base cost

c = resource complexity cost

### 8.3.5 Contingency Specification

In the event that a high level of complexity is present within an activity in a critical path, a contingency is calculated. The contingency values in Table 8-1 were defined by industrial collaborators involved in this research for application to the resource complexity cost.

**Table 8-1:** Contingency for Complexity Cost

| Lower Uncertainty Value | Upper Uncertainty Value | Value (%) |
|---|---|---|
| 1 | 2 | 5 |
| 2 | 3 | 15 |
| 3 | 4 | 20 |
| 4 | 5 | 35 |
| 5 | 7 | 50 |

The uncertainty score derived from the evaluation of uncertainty for each complexity dimension is used to drive the selection of a contingency percentage. The highest uncertainty score will always be seven. Therefore each contingency is determined by a lower to upper uncertainty score range. In

Figure 8-5, the process for deriving contingency is illustrated. This contingency derived for the relevant complexity would be added to the resource complexity cost. The contingency values are non-linear.


**Figure 8-5:** Contingency Production Flow

### 8.3.6 Complexity Cost Estimation with Monte Carlo Simulation

The cost estimation for resource complexity is simulated using Monte Carlo in AnyLogic. The cost distribution is transferred through an interface program into a tool called minitab which presents the cost distributions on histograms. A normal distribution is selected as described in Section 8.2.9.

### 8.3.7 Revise System Requirements

The system requirements and scope as defined in the WBS are revised in this step of the framework. The project scenario is reviewed and the scope is amended according to the resource complexity cost estimate. The three-point estimate for the project activity duration is reassessed in the event that the project schedule has an impact on the cost estimate. A scenario analysis may be performed by estimating resource complexity costs according to different schedules. The resource rates are also revised and adjusted as perceived necessary. In the event that the cost estimate is perceived too high for certain resources, either the number of resources or their effort may be reduced. Subsequently, the cost estimation process will be re-executed in order to observe the impact of the changes which may have occurred as a result of the revision. This whole process enables an organisation to manage and control their resource complexity which ultimately supports cost control and reduction.

## 8.4 Validation Results of Complexity Costing Framework

This section highlights the requirements and results from the validation and refinement sessions.

**Uncertainty Assessment using NUSAP Pedigree Matrix**

Expert 19 from Company I which is a risk analysis consultancy commended using the NUSAP pedigree matrix for uncertainty evaluation. Expert 19 is a functional ERP consultant and has a total of 10 years ERP work experience. Expert 19 stated that the assessment is excellent because it ensures rigour in the estimating process for the complexities, in relation to the uncertainty surrounding the estimates. All other participants, except Expert 17 from Company B, an aerospace organisation, clamoured the same compliments. Expert 17 is an ERP programme manager from an aerospace and defence company.

**Activity Duration and Cost Accuracy Range**

Experts from Company C, a reputable ERP implementation consultancy, suggested that the use of duration in the proposed WBS would require a column which indicates total effort. This total effort will be the product of the number of resources and duration of activity. Additionally, Company C advised that a well-defined process does not currently exist in the ERP industry for the application of a cost accuracy range to an estimate. Therefore, defining this concept in C-REACT will be embraced in ERP implementations. Company C suggested that this range should be introduced as a standard method in ERP implementations.

**WBS Scenario Analysis Functionality**

Company B proposed that the WBS be enabled to estimate resource complexity costs according to different scenarios which are determined by the project activity. Therefore, the WBS should possess the capability to switch activate and deactivate project activities according to the activity which applies in a certain scenario. This enables various scenarios to be analysed based on the maturity of the project activities. The scenario analysis will have an impact on decision-making as a result of the complexity cost.

**WBS Critical Path Specification**

Company C suggested that the WBS should be provided with a function which enables the specification of activities in a critical path. Therefore, the critical path may be activated or deactivated for the relevant activity. This will allow additional actions to be performed in the event that an assessed complexity level within the same activity is high. The identification of complexity in critical path activities will influence the resource complexity cost.

**WBS Three-Point Estimating and Default Duration**

In the semi-structured interviews, the participants agreed unanimously to implement a three-point estimate for specifying activity duration. This method caters for uncertainty in duration. Furthermore, the participants suggested that a default duration be implemented in the WBS.

**Contingency for High Level of Complexity**

Company B conceded that in the event that a high level of complexity is presented by any complexity factor which occurs in a critical path activity, the actions of the ERP adopting organisation are unknown. They might decide to hire additional resources, delay the project or cancel it altogether. Either way, this presents additional uncertainty in the ERP implementation. Consequently, the participants of the validation process suggested that contingency should be added to the complexity cost.

**Simplification of Complexity Estimation Process**

Expert 16 who is a cost modelling specialist from Company C suggested simplification in his terms, of complexity calculation. The proposed calculation is to estimate the time it will take for a task (parametric estimating using cost driver rates to estimate the time), and if the actual exceeds this, then the difference in time is calculated. And the cost for this time will be the complexity cost. The researcher advised that this method was initially considered, but was dismissed because it lacked the rigour and structure in the current framework.

## 8.5 Summary

This chapter presents the ERP resource complexity costing framework. This framework is embedded in the ERP resource of complexity assessment and costing tool (C-REACT). The essence of the framework is to enable the cost estimate of the complexities encountered by project resources in an ERP implementation. The estimate serves as a rough order of magnitude.

Section 8.2 highlights the methodology which was adopted in developing the complexity costing framework. The key features which were considered in framework development are the WBS for project scheduling, expert judgment with activity-based costing and parametric estimating, three-point estimating for activity durations, AHP for complexity assessment, NUSAP pedigree matrix and manual scoring for uncertainty evaluation, and complexity breakdown structure which incorporates the complexity taxonomy for complexity identification. Other factors highlighted are the mapping of complexities to cost drivers, defining a contingency in the event of a high complexity scenario, and producing a cost distribution for resource complexity costs using Monte Carlo simulation. Dynamic cost estimating of resource complexities is also highlighted and it is accomplished using agent-based modelling.

Section 8.3 presents the complexity costing framework which entails the definition of the work breakdown structure, the complexity identification and assessment, mapping complexity types to cost drivers to enable complexity measurement and costing, the implementation of a dynamic process for estimating complexity costs for project resources through agent-based modelling, specifying contingency in the presence of high complexity scenarios, producing a complexity cost distribution using Monte Carlo scenario, and adjustments to the project requirements.

The next chapter presents the tool within which the C-REACT framework is embedded, and its validation results.

# 9 IMPLEMENTATION AND VALIDATION OF COMPLEXITY OF RESOURCE AND ASSESSMENT COSTING TOOL

## 9.1 Introduction

In Chapter 7 and Chapter 8, the two frameworks embedded in the complexity of resource and assessment costing tool (C-REACT) were presented. C-REACT enables a potential ERP adopting organisation to evaluate and cost the complexities which are experienced by the resources in a typical ERP implementation project team. The framework is used in the needs identification stage of an ERP whole life cycle, and its application allows an organisation to understand, anticipate, and prepare to control and reduce potential complexity and cost. The purpose of this chapter is to present the implementation of C-REACT which is developed by combining the features of Microsoft Excel and a simulation tool called AnyLogic. The modelling technique adopted in AnyLogic is agent-based modelling (ABM). Subsequently, the validation of the framework by means of three case studies is discussed. A qualitative validation with experts from different industries is also described. This chapter fulfils the research objective to verify and validate C-REACT through real life industrial case studies and experts' opinion.

In Section 9.2, the research methodology which was adopted for validating the C-REACT is presented. Section 9.3 describes the implementation of the first two modules of C-REACT framework in a tool using Microsoft Excel and Visual Basic for Applications. The system architecture of the tool is illustrated in this section. Additionally, the implementation and system architecture of the third module of C-REACT are also illustrated. In Section 9.4, the validation of the tool through three case studies is discussed. Section 9.5 presents the validation of the tool through expert opinion. Section 9.6 summarises this chapter.

## 9.2 Research Methodology for the C-REACT Tool Validation

The validation of C-REACT was conducted through three case studies and the judgment of eight experts from industry. One of the case studies was presented by an ERP project manager from a prestigious UK ERP consultancy, who made a substantial contribution to the conceptual validation of the framework. His case study is based on the aerospace ERP project which he is involved in. The other two case studies were produced by an electrical manufacturing organisation, and by the researcher based on a UK retail and investment bank where she had worked previously as a SAP consultant. The electrical manufacturer did not participate in any previous validation or interviews concerning C-REACT. The essence of introducing a new participant into the validation process was to disable bias by enabling the expressions of new and different perspectives.

The tool validation conducted by the aerospace and electrical manufacturing organisations entailed the researcher presenting the details of the tool to both companies by means of a WebEx teleconference, and a face-to-face meeting. The details of the industrial collaborators of the framework validation are provided in Table 9-1. Each expert is provided with a unique identification. Each interview lasted two hours. The features and functionality of the tool were demonstrated to each participant using default data. The defaults were produced by the ERP consulting organisation in the conceptual validation of the C-REACT framework. These defaults are a reflection of authentic project data, and they were validated by the other participants of the validation to ensure suitability for the tool. Each demonstration lasted for a minimum of two hours and the researcher clarified all the questions asked by the participants. Upon completion of the tool presentation, each participant was prepared to input their own data in the tool. In order to enable this, the researcher emailed a copy of the tool to each participant. During the process of inputting their own data, any questions which required clarification was answered by the researcher either through email or a telephone conversation. Upon conclusion of data input by the participants, a meeting was held with the researcher to review the data, analyse and discuss the results, and fill out the validation questionnaire (see Appendix A.4).

Some of the questions in the validation questionnaire are:

- How logical are the complexity concepts and features in the framework?
- Is the framework suitable for the needs identification stage of the whole life cycle?
- Please comment on how generalisable the framework is for your industry
- How would the framework benefit complexity considerations?
- What are the potential challenges in using and implementing the tool?
- Evaluate the output from the tool based on data from the case study

**Table 9-1:** Participants of C-REACT Tool Validation

| Expert | Organisation | Position in Organisation | Position in ERP Project | Years of Experience | Case Study/Tool |
|---|---|---|---|---|---|
| Expert 12 | Company J | SAP Functional Consultant | SAP Functional Consultant | 14 | Tool |
| Expert 13 | Company J | Authorisations Specialist | Authorisations Specialist | 6 | Tool |
| Expert 17 | Company B | IT Manager | Project Manager | 16 | Tool |
| Expert 23 | Company K | Project Manager of IT for Supply Chain | Process Owner | 15 | Tool |
| Expert 24 | Company K | Technical Head Programme Management | Project Manager | 25 | Tool |
| Expert 25 | Company K | Project Director of IT for Supply Chain | Process Owner | 28 | Tool |
| Expert 28 | Company N | IT Program Manager | Project Manager | 20 | Case study |
| Expert 29 | Company L | Project Manager | Project Manager | 20 | Case study |

The results of the analysis performed on the responses from the tool validation are provided in Sections 9.4 and 9.5.

## 9.3 Implementation of the C-REACT Framework

The C-REACT framework is embedded in a tool using Microsoft Excel, Visual Basic for Applications (VBA), and Agent-Based Modelling (ABM) developed in AnyLogic. The tool reflects the ERP complexity assessment and ERP complexity costing frameworks which synthesise the overall C-REACT framework. These frameworks were described in Chapter 7 and Chapter 8. This section focuses on the structure of the first two modules. The architecture is illustrated in Figure 9-1.

There are three integrated modules developed in C-REACT in order to satisfy the requirements of the framework. The modules are:

- Module 1 - Project scheduling and resource allocation which enables the specification of the relevant WBS elements for the estimating of resource base costs. This module is embedded in Microsoft Excel and developed using VBA. It fulfils stage 1 of the resource complexity costing process.
- Module 2 - Complexity assessment which drives the process of complexity identification, uncertainty evaluation, complexity significance specification, and complexity scoring. The outputs of this process derive a complexity measure for costing. Microsoft Excel and VBA are used to develop this module. This module fulfils stages 2 and 3 of the resource complexity costing framework, and all the stages of the complexity assessment framework.
- Module 3 - Dynamic resource cost estimation which calculates and simulates the resource base costs and resource complexity costs through agent-based modelling. This model is developed in AnyLogic software which is an object-oriented java-based simulation tool. According to Buxton *et al.* (2006), AnyLogic is ideal for ABM logic. It fulfils stages 4, 5 and 6 of the resource complexity costing framework.

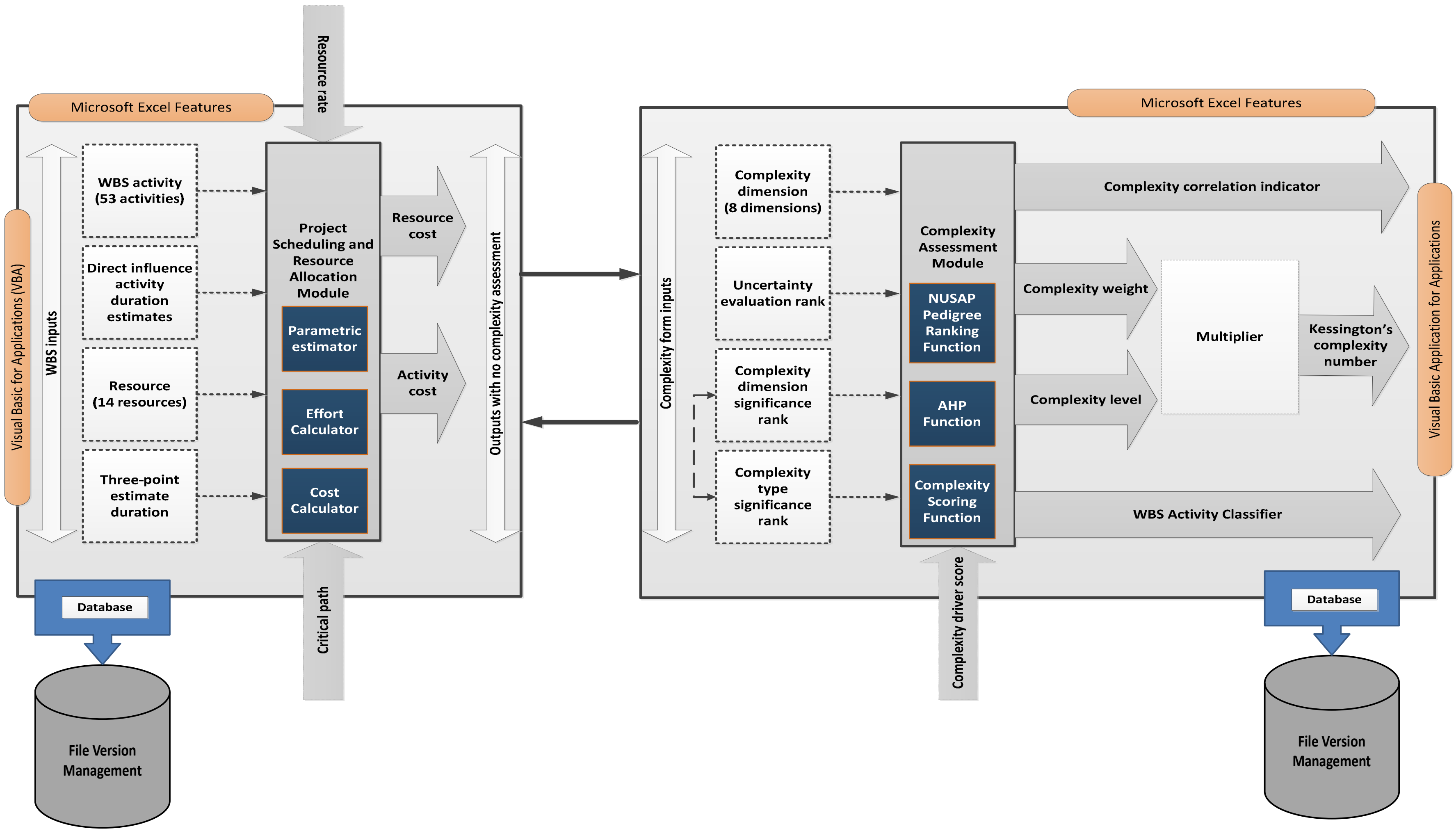



**Figure 9-1:** C-REACT System Architecture – Modules 1 and 2

### 9.3.1 Implementation of C-REACT Module 1 and Module 2

The first two modules of C-REACT are developed in Microsoft Excel. The programming language used is visual basic for applications (VBA). The first module enables scheduling of the potential ERP implementation project as well as its resource allocation. The second module drives the identification and assessment of ERP implementation complexity with an evaluation of its uncertainty.

The Project Scheduling and Resource Allocation module accepts inputs from the user in three different screens as illustrated in Table 9-2. The complexity assessment module accepts inputs on the screens outlined in Table 9-3.

**Table 9-2:** Project Scheduling and Resource Allocation Module Inputs

| Screen | Inputs |
|---|---|
| **Direct Influence Cost Driver Estimates** | Quantity of direct influence cost driver |
| **Project Schedule (WBS)** | Fifty-three activities<br>Fourteen resource types<br>Three-point estimate effort for each activity<br>Critical path indicator for the relevant activity |
| **Resource Profile (resource rates)** | Rate for each resource |

**Table 9-3:** Complexity Assessment Module Inputs

| Screen | Inputs |
|---|---|
| **Complexity Dimension Specification** | Complexity dimensions |
| **Uncertainty Evaluation for Complexity** | Uncertainty ranks |
| **Significance Assessment of Complexity Dimensions** | Pairwise comparison ranks for complexity dimensions |
| **Complexity Type Significance Assessment** | Pairwise comparison ranks for complexity types |
| **Complexity Scoring Form** | Complexity level scoring for each cost driver linked to complexity type |

The functions which were developed in the Project Scheduling and Resource Allocation module using a combination of macros and formulae are as follows:

a) The parametric estimator, which calculates a most likely effort for each direct influence cost driver.
b) The effort calculator in the project schedule screen
c) The cost calculator which calculates and outputs the cost of each resource, each activity, each phase and the total project in the project schedule

The functions in the complexity assessment module which were developed as a combination of macros and formulae are:

a) NUSAP pedigree ranking function which calculates and outputs the uncertainty score.
b) AHP function which calculates and outputs the weights for the pairwise comparisons for each complexity dimension and complexity type
c) Complexity scoring function which scores and outputs each complexity type according to its level of complexity

The complexity level is multiplied by the complexity weight to produce a score called Kessington's complexity number (KCN) for each complexity type. This complexity number is used in the costing process of module 3. A WBS complexity matrix indicating the KCN for each project activity is presented. A screenshot of this matrix is presented in Section 7.3.5. Additionally, a complexity correlation matrix is produced, indicating the complexities which may be effected in the event that certain complexities arise. A screenshot of a complexity correlation matrix is illustrated in Section 7.3.6.

The flowchart of the screens in the complexity of resource and assessment costing tool (C-REACT) is presented in Figure 9-2. The key screens and associated fields are described below. The full details of all the screens are provided in the user guide (see Appendix D).

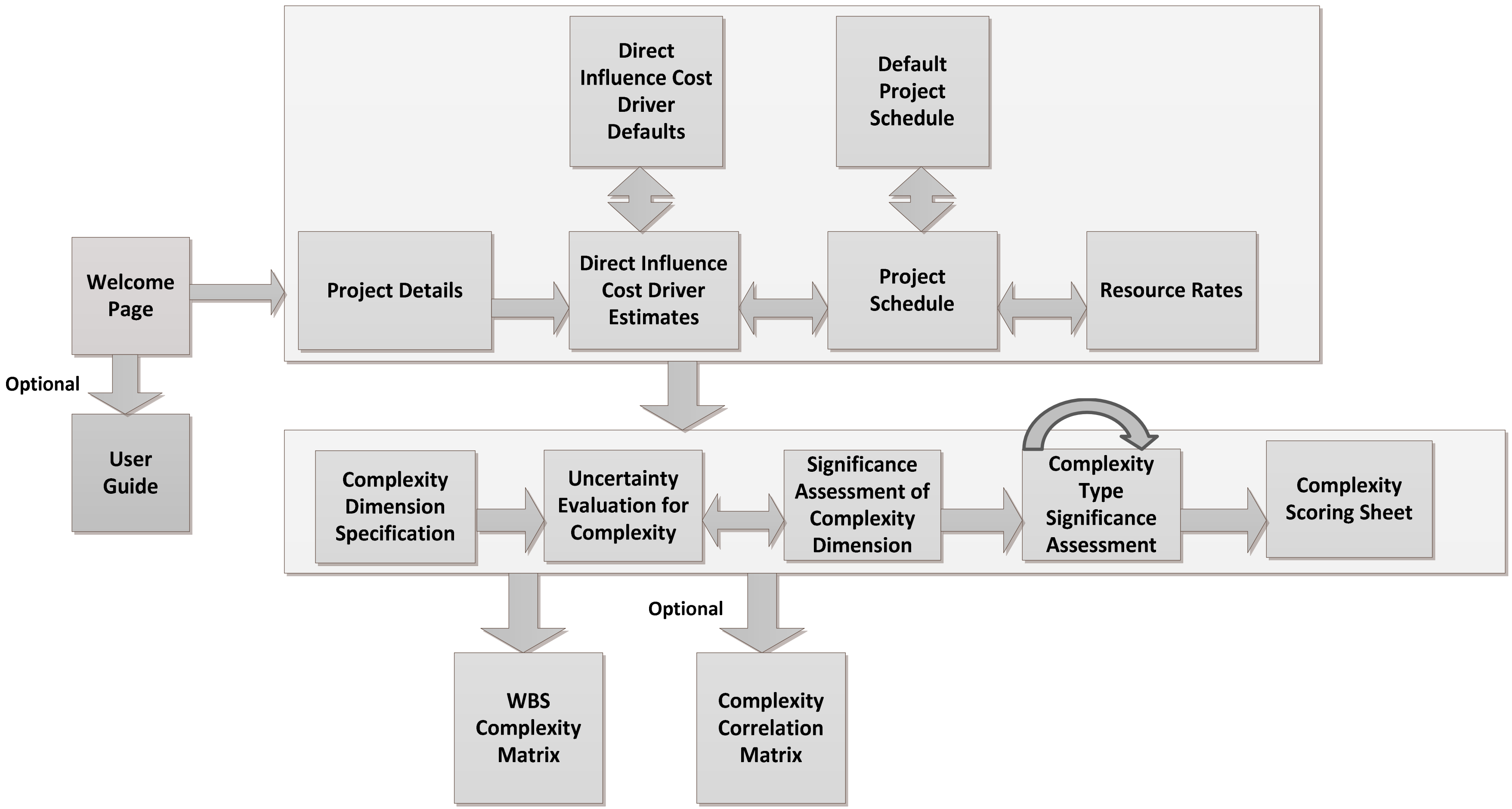



**Figure 9-2**: Flowchart for C-REACT

#### 9.3.1.1 Project Schedule

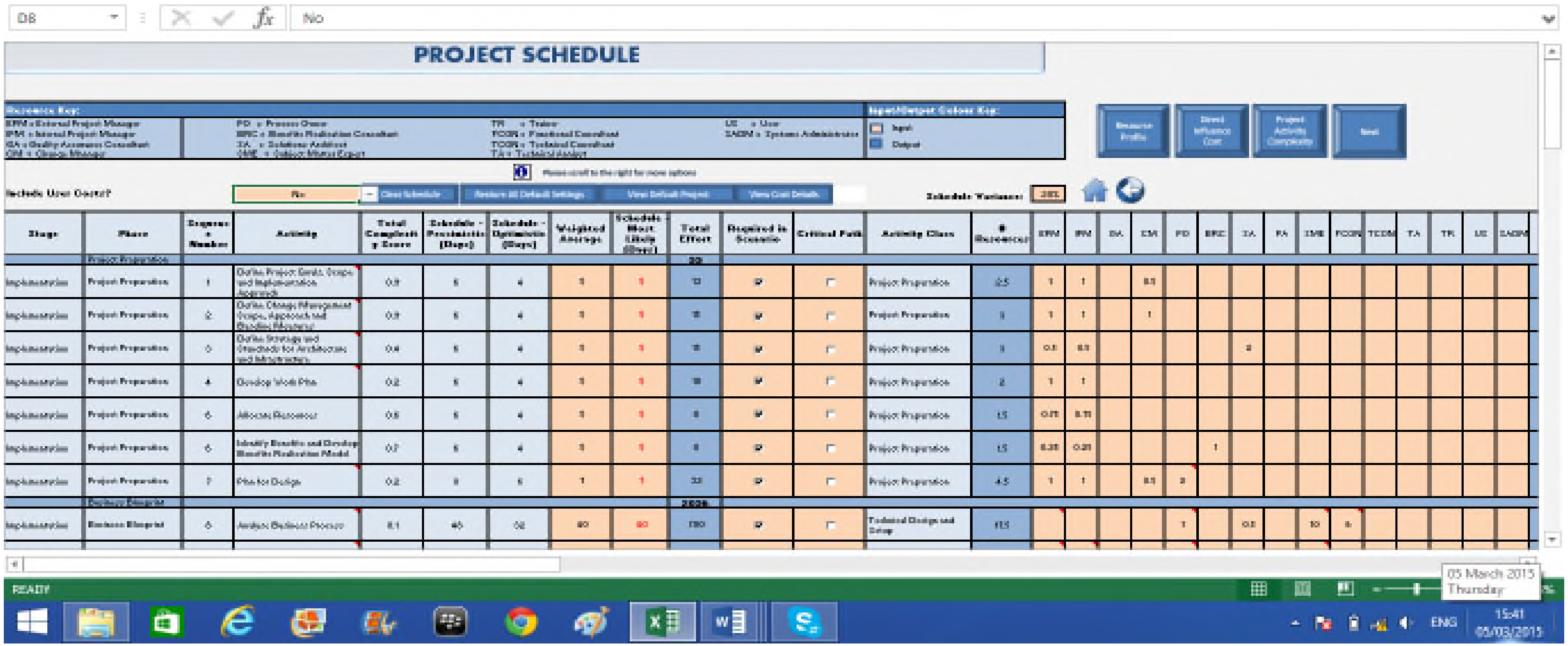
The project schedule submenu presents three options to the user, each leading to a different screen. The screens fulfil the project schedule and resource allocation module in the architecture depicted in Figure 9-1. The screens are; direct influence cost driver estimates, resource rates and project schedule (WBS). The WBS screen which is labelled project schedule, accepts the user's inputs to specify the project activities, their durations, and resources allocated to the activities. It also outputs the cost for each resource, activity and phase. A WBS screenshot is displayed in Figure 9-3. The details of this screen are provided in Appendix D. In terms of the direct influence cost driver estimates screen, it presents the rates which would be used to estimate the most likely duration for the activities which the specified cost drivers have a direct influence on. The duration automatically updates the relevant WBS activity and influences the calculation of the pessimistic and optimistic durations by applying the specified variance in the WBS. The default variance is 20%.

#### 9.3.1.2 Complexity Identification and Assessment

This is a submenu which presents options to select screens that fulfil the complexity assessment module of the architecture in Figure 9-1. The screens consist of processes requiring inputs from the user and reports displaying outputs from the processes. The processes are; (1) complexity dimension significance, (2) uncertainty assessment, (3) complexity dimension significance assessment, (4) complexity type significance assessment, and (5) complexity scoring. The reports are WBS complexity matrix, complexity correlation matrix and complexity charts.

**1. Complexity Dimension Significance**

This screen allows an expert to identify and specify the complexity dimensions in their costing scenario. A macro is developed to present the first five complexity dimensions as mandatory. The macro also ensures that out of the




**Legend:** EPM = External Project Manager, IPM = Internal Project Manager, QA = Quality Assurance Specialist, CM = Change Manager, PO = Process Owner, BRC = Benefits Realisation Specialist, SA = Solutions Architect, SME = Subject Matter Expert, FCON = Functional Consultant, TCON = Technical Consultant, TA = Technical Analyst, TR = Trainer, US = User, SADM = Systems Administrator

**Figure 9-3:** Screenshot of Work Breakdown Structure

11 complexity dimensions presented to the user they are only allowed to select three from the remaining six optional complexity dimensions. An error message is output in the event of attempting to select more than six dimensions. A screenshot of the complexity dimension specification is presented in Chapter 7.

**2. Uncertainty Assessment**

The uncertainty for the estimates provided for each of the eight initially specified complexity dimensions is evaluated on this screen. It presents three criteria (basis of estimate, rigour in assessment, and level of validation) to the user, each of which expects a validated value (1,3,5, or 7). A formula is developed to calculate an average score across the scores for the three criteria. This average value serves as the uncertainty score. A macro is developed to only display the eight complexity dimensions which were selected on the complexity dimension significance screen.

**3. Complexity Dimension and Type Significance Assessment using AHP**

This screen is used to assess the significance of each complexity dimension in relation to costing. The user inputs the ranks (1,3,5,7, or 9) for each of the eight complexity dimensions already selected. A macro is developed to present the user with the significance assessment screens for the complexity types associated with these complexity dimensions. Therefore, every complexity dimension is compared against another to derive a weight. This process of pairwise comparison is achieved using analytical hierarchy processing (AHP), and also applies to the complexity types. A separate screen is created for solely calculating the results of the pairwise comparison. This screen uses both macros and formulae. A weight is generated from this screen for each complexity dimension and complexity type. The relevant weights are transferred to their corresponding dimensions and types on the significance assessment screens. A screenshot of the significance assessment for complexity dimensions is illustrated in Figure 9-4. The details of the remaining screens are provided in Appendix D.

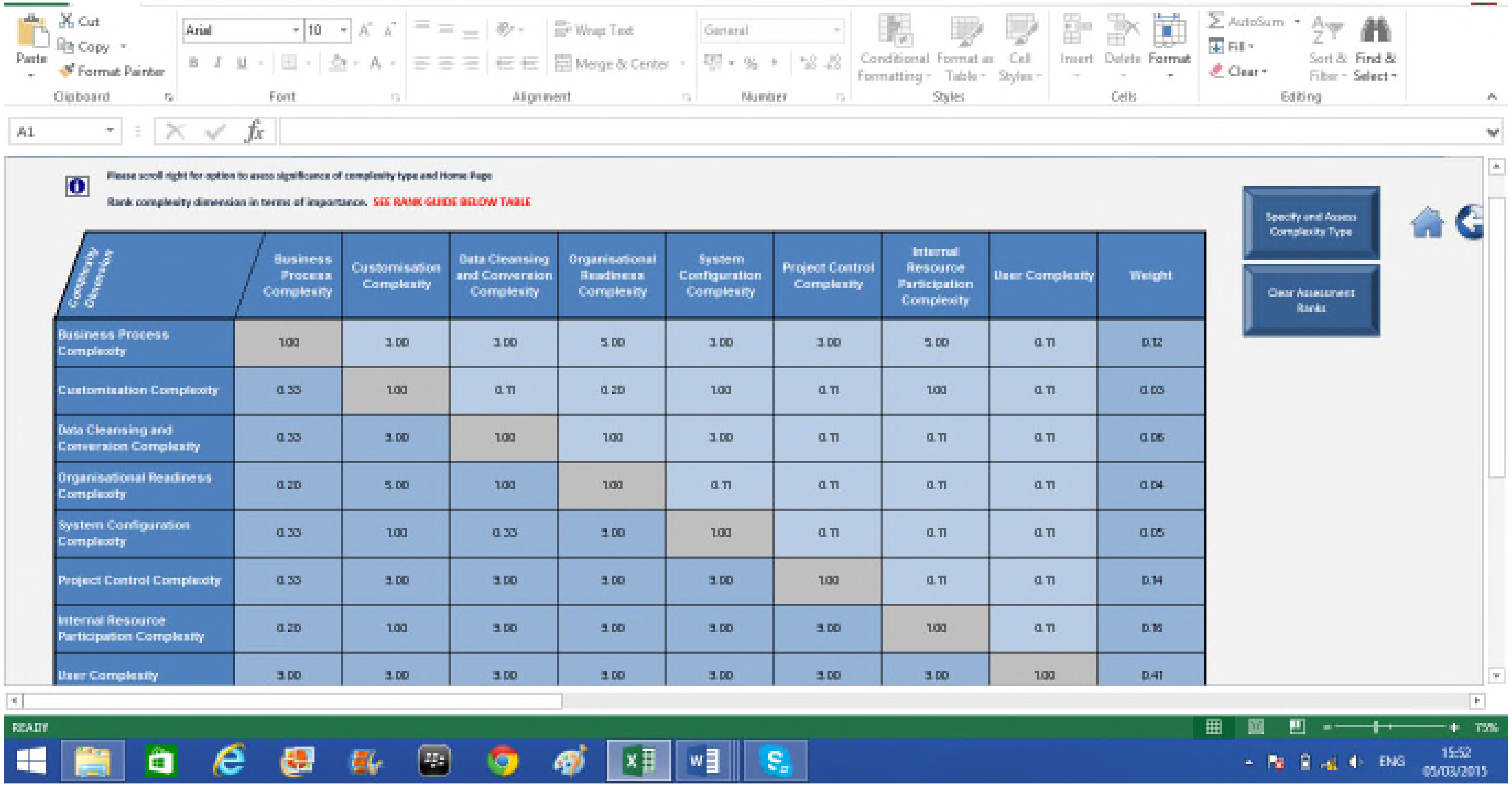



**Figure 9-4:** Screenshot of Significance Assessment of Complexity Dimension

### 9.3.2 Implementation of C-REACT Module 3

This research seeks to develop a tool that simulates the cost of resource complexities inherent in ERP implementations. Agent-based modelling (ABM) technique was selected for this purpose for reasons discussed in Chapters 2 and 8. Literature review highlights that agent systems represent a new way of analysing, designing and implementing complex software systems. This applies to this research as it addresses the complexity of ERP implementations. ABM enables the ability to address individual complex behaviours and emergent patterns. Agents may be modelled as organisations, individuals or projects. In this research, the resources on the ERP project team are represented as individual agents in ABM, each possessing its own behaviour. Agent-based models also describe systems and organisations as activities. Hence the project activities which are specified in the work breakdown structure of C-REACT are properly modelled in ABM using this technique. Furthermore, ABM may be used in circumstances where the level of complexity is not known beforehand. Additionally, due to its capability of emergence, it may lead to nonlinear individual agent behaviours. These characteristics offered by ABM are well suited to this research. The final complexity score which is the Kessington's complexity number (KCN) is not known for each type of complexity until the completion of the assessment. Therefore the complexity cost for each resource cannot be estimated until KCN is presented. However, one of the disadvantages of an agent-based model is that the accuracy of its inputs could vary thereby affecting the accuracy of outputs.

The application of agent-based modelling in the dynamic costing of ERP implementation resource complexities will introduce a new dimension to costing techniques in research and industry. The simulation of ERP complexity cost estimation will enable organisations to visualise the growth or reduction of complexity and its impact on cost as it occurs. This will allow dynamic decision-making by potential ERP adopters in their contemplation to implement ERP and in their attempt to budget for future ERP implementations. The dynamism of

ABM also encourages scenario analysis, thereby allowing a potential ERP adopter to run several scenarios through the model. This produces a richer and more robust basis for decision-making. Figure 9-5 presents the architecture of the third module of C-REACT. The architecture constitutes the following components:

1. Agents
2. Statecharts
   - project activities
   - WBS activities by resource for each agent
3. Interface from Module 1 and Module 2 of C-REACT
4. Messaging
5. Calculation rules for resource base cost
6. Calculation rules resource complexity cost
7. Resource complexity cost estimates:
   - resource base costs
   - resource complexity cost
   - total resource cost
8. Monte Carlo simulation

### 1. Agents

In the third module of C-REACT, agents are created which represent the following resource types:

- External project manager (EPM)
- Internal project manager (IPM)
- Change manager (CM)
- Quality assurance consultant (QA)
- Process owner (PO)
- Benefits realisation consultant (BRC)
- Solutions architect (SA)
- Subject matter expert (SME)

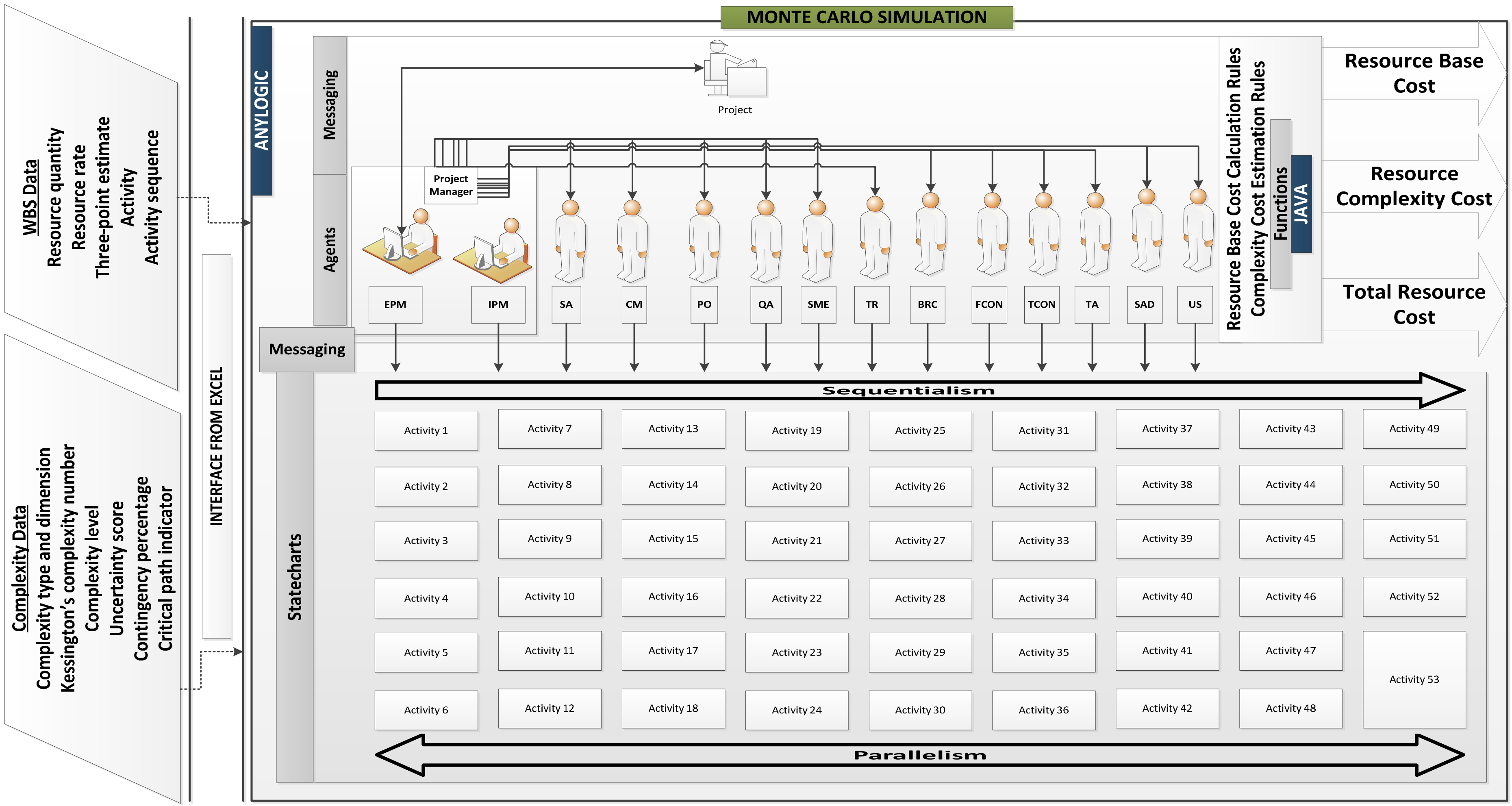



**Figure 9-5:** C-REACT System Architecture – Module 3

- Functional consultant (FCON)
- Technical consultant (TCON)
- Technical analyst (TA)
- Trainer (TR)
- User (US)
- System administrator (SAD)
- Project

Every agent has its own set of behaviours which are modelled as the activities within which they work. These activities are pre-defined in the statechart for each agent.

**2. Statecharts**

Each agent is modelled with a statechart which is a representation of the states of the agent at pre-specified times. The project activities illustrate the behaviours of the agents, and they are defined within the statechart. An illustration of an example statechart for a functional consultant agent is presented in Figure 9-6.

The statechart is composed of states and transitions. Each state represents the start and end of the activity within which a resource is working. Each transition is the duration of the actual activity. The states within each statechart is pre-defined and not created dynamically. Therefore, the states and transitions reflect the activities in the WBS of C-REACT which consists of fifty-three activities. This means that any activity which is added to the framework must be manually added to the statechart. The majority of these activities are executed sequentially. However, some of these activities are run in parallel. Although statecharts are not efficient in parallelism. Consequently, this part of the implementation was the most challenging and time-consuming. However, it was imperative that the researcher incorporated parallelism as specified in the WBS in order to avoid over-allocation of resources which will generate an inflated cost estimation.

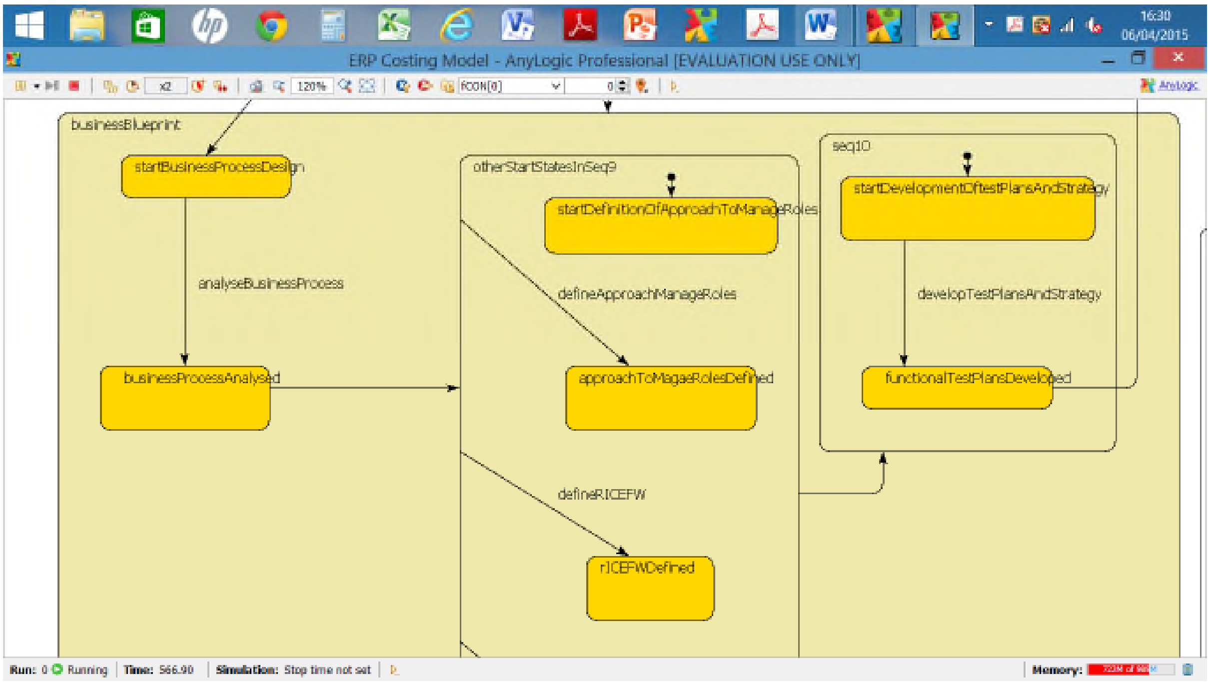



**Figure 9-6:** Statechart for Functional Consultant Agent

States are created within states to enable parallelism in C-REACT. Managing this kind of implementation is cumbersome. The other method that would accommodate parallelism efficiently is the use of events in AnyLogic. This approach is also very dynamic. However, the researcher preferred to use statecharts to enable a clear visualisation of the agents as they work through their activities. This enables better judgment and decision-making. In the event that activities are added to the WBS, a new version of C-REACT must be created and released. In this new version, the statechart will be amended to reflect the new activities.

### 3. Interface from Module 1 and Module 2 of C-REACT

AnyLogic provides a functionality which enables a model to read inputs from external applications like microsoft excel, and to output data to these applications. The feature which enables interfacing in AnyLogic is known as connectivity. This feature is implemented in C-REACT. As the simuation starts, each agent accesses a microsoft excel input file which is the output of module 2 and module 3 of the C-REACT tool. The inputs into the resource complexity cost estimation model are; (1) the work breakdown structure data which comprises of the WBS activity, three-point effort estimate for each activity, activity sequence, resource quantity and resource rate, and (2) the complexity data which constitutes Kessington's complexity number (KCN), complexity type and dimension, complexity level, uncertainty score for complexity estimates, contingency percentage and the critical path indicator

## 4. Calculation Rules for Resource Base Cost and Resource Complexity Cost

The resource base cost is the cost of each resource within each activity and all activities without complexity assessment. Although this estimate is already provided in the complexity assessment tool as part of the project scheduling process, the complexity cost estimation module recalculates it by taking uncertainty into consideration. The second part of the complexity cost estimation module is the calculation of the complexity cost for each resource. Figure 9-7 illustrates the algorithm for the complete cost estimation process. The cost calculation process is described in Chapter 8. The algorithm in Figure 9-7 is applied to fourteen agents. The code which embeds the algorithm is written as a function in Java (see Appendix E). Upon completion of the resource base cost and complexity cost calculation, the tool outputs three values:

- resource base cost
- resource complexity cost
- total resource cost

These outputs are presented in bar charts as illustrated in the user guide. However, a screenshot of the resource complexity cost bar chart is presented in Figure 9-8. It displays the complexity cost for each resource.

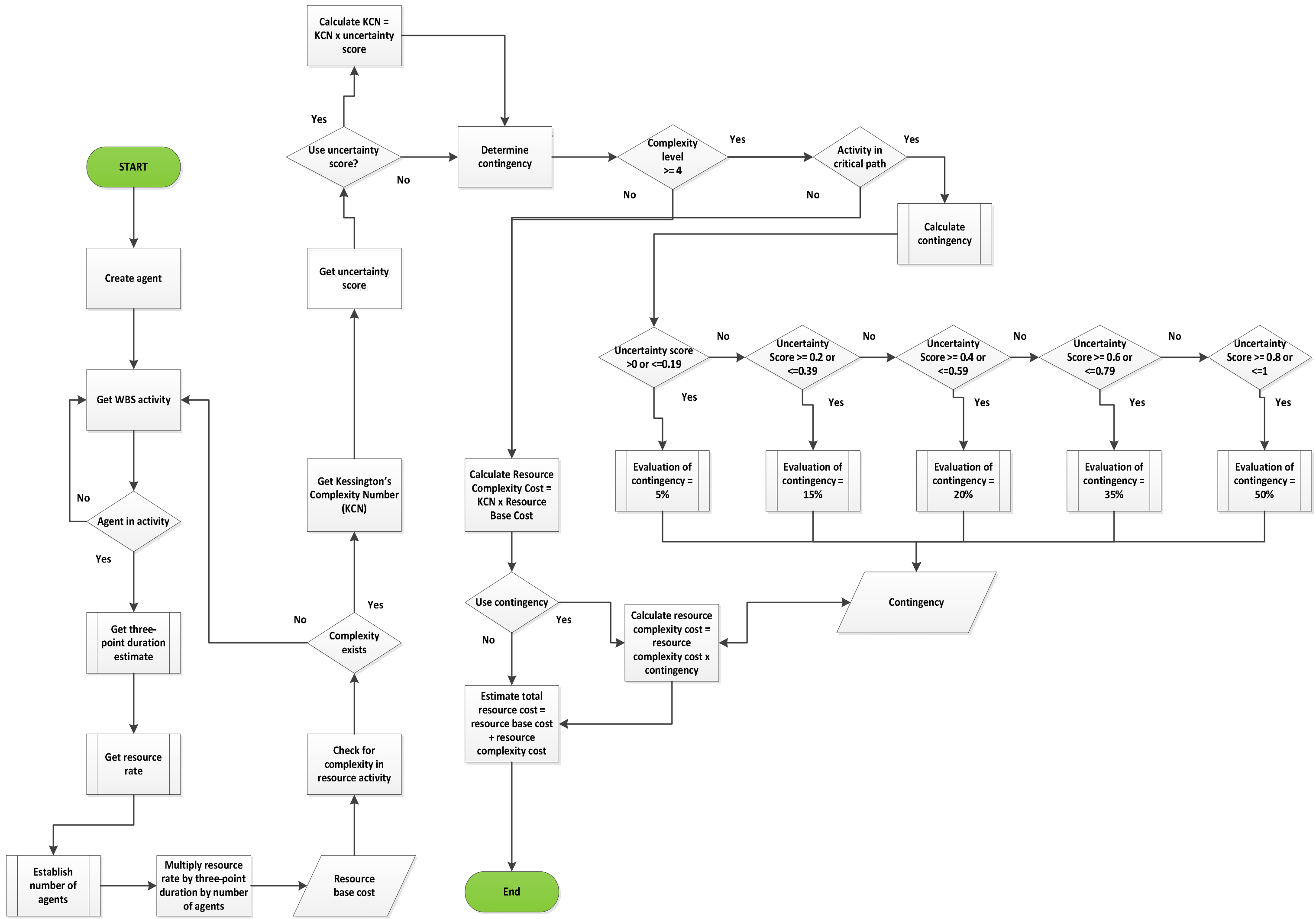



**Figure 9-7:** Algorithm for Complexity Cost Estimation


| **Resource Description:** | | |
|---|---|---|
| EPM: External Project<br>IPM: Internal Project Manager<br>QA: Quality Assurance Specialist<br>CM: Change Manager<br>PO: Process Owner | BRC: Benefits Realisation Specialist<br>SA: Solutions Architect<br>SME: Subject Matter Expert<br>FCON: Functional Consultant | TCON: Technical Consultant<br>TA: Technical Analyst<br>TR: Trainer<br>US: User<br>SAD: System Administrator |

**Figure 9-8:** Screenshot of Resource Complexity Cost

## 5. Monte Carlo Simulation

The outputs which are obtained as resource complexity cost estimates are run through a Monte Carlo simulation one thousand times in order to account for uncertainty. The cost distributions which were applied using a tool known as minitab, are normal and log-normal distributions.

The researcher verified C-REACT. Thereafter, she requested for the tool to be further verified by Expert 30, who is a research fellow from university of Southampton working on complexity science in relation to agent-based modelling. Once he had verified the tool, one of the comments he made on Module 3 is that the code was sampling inefficiently from the triangular distribution for the three-point estimates applied to each activity. He suggested that the old logic (min, max, mode) be switched to the new logic (min, mode, max). The researcher made the relevant changes. His next feedback was that there was a large amount of hardcoding in the model, which could slow down its processing. I advised him that one of the reasons for the hardcoding was to accomplish parallelism in the resource execution of simultaneous activities. He suggested the use of events, but conceded that the visualisation would not be as effective as using statecharts. Therefore, the researcher retained the application of hardcoding.

## 9.4 Tool Validation through Case Studies

Three case studies were used to validate C-REACT across three organisations. Additionally, expert judgment was used to validate the framework. The first case study was provided by the researcher based on a high complexity ERP implementation she was involved in. This implementation was conducted in a large UK retail bank. The second case study applied to a large aerospace manufacturing organisation which is in the process of commencing an ERP implementation. The third case study was for a large organisation in the electronics manufacturing industry. This company has already implemented an ERP system in a very high complexity environment. They are currently considering the adoption of an additional module. Table 9-4 presents a synthesis of the WBS activity and resource specification for all three case studies, whilst Table 9-5 presents a cross-case study synthesis of the preliminary cost estimates. These estimates are generated in Module 1 of C-REACT, and exclude assessed complexity.

**Table 9-4:** WBS Specification for Resources and Activities

| Resource Type | Case Study 1 | | Case Study 2 | | Case Study 3 | |
|---|---|---|---|---|---|---|
| | In Critical Path Activity | Number of Critical Path Activities | In Critical Path Activity | Number of Critical Path Activities | In Critical Path Activity | Number of Critical Path Activities |
| EPM | No | N/A | No | N/A | Yes | 10 |
| IPM | No | N/A | No | N/A | Yes | 10 |
| QA | No | N/A | No | N/A | Yes | 1 |
| CM | No | N/A | No | N/A | Yes | 5 |
| PO | No | N/A | No | N/A | Yes | 9 |
| BRC | No | N/A | No | N/A | Yes | 6 |
| SA | No | N/A | No | N/A | Yes | 4 |
| SME | No | N/A | No | N/A | Yes | 10 |
| FCON | No | N/A | No | N/A | Yes | 10 |
| TCON | No | N/A | No | N/A | Yes | 6 |
| TA | No | N/A | No | N/A | Yes | 6 |
| TR | No | N/A | No | N/A | Yes | 4 |
| SADM | No | N/A | No | N/A | Yes | 22 |

**Legend:** EPM = External Project Manager, IPM = Internal Project Manager,QA = Quality Assurance Specialist, CM = Change Manager, PO = Process Owner, BRC = Benefits Realisation Specialist, SA = Solutions Architect, SME = Subject Matter Expert, FCON = Functional Consultant, TCON = Technical Consultant, TA = Technical Analyst, TR = Trainer, US = User, SADM = Systems Administrator

**Table 9-5:** WBS Preliminary Cost Estimates

| Resource Type | Case Study 1 | | Case Study 2 | | Case Study 3 | |
|---|---|---|---|---|---|---|
| | Resource Rate per Day (£) | Total Cost per Resource (£) | Resource Rate per Day (£) | Total Cost per Resource (£) | Resource Rate per Day (€) | Total Cost per Resource (€) |
| EPM | 600 | 201,300 | 600 | 201,100 | 800 | 354,000 |
| IPM | 500 | 167,750 | 500 | 169,250 | 600 | 283,500 |
| QA | 250 | 10,000 | 250 | 10,000 | 250 | 8,750 |
| CM | 400 | 45,760 | 300 | 35,370 | 400 | 112,800 |
| PO | 400 | 138,400 | 400 | 128,660 | 400 | 279,000 |
| BRC | 400 | 48,400 | 500 | 60,500 | 400 | 38,000 |
| SA | 500 | 47,500 | 500 | 41,350 | 800 | 324,000 |
| SME | 100 | 236,300 | 100 | 130,625 | 800 | 3,104,000 |
| FCON | 750 | 2,001,000 | 750 | 881,550 | 800 | 3,652,000 |
| TCON | 500 | 854,500 | 500 | 500,000 | 600 | 1,362,000 |
| TA | 100 | 171,900 | 100 | 100,000 | 600 | 1,242,000 |
| TR | 500 | 47,500 | 500 | 47,500 | 600 | 78,000 |
| SADM | 400 | 179,800 | 100 | 47,100 | 400 | 200,000 |
| **TOTAL RESOURCE COST =** | **£4,150,110** | | **£2,355,005** | | **€11,038, 050** | |

**Legend:** EPM = External Project Manager, IPM = Internal Project Manager, QA = Quality Assurance Specialist, CM = Change Manager, PO = Process Owner, BRC = Benefits Realisation Specialist, SA = Solutions Architect, SME = Subject Matter Expert, FCON = Functional Consultant, TCON = Technical Consultant, TA = Technical Analyst, TR = Trainer, US = User, SADM = Systems Administrator

### 9.4.1 Case Study 1 : ERP in Banking

This case study covers the implementation of an ERP solution for a large retail bank in the United Kingdom. The bank owns over one thousand branches. The organisation was in the process of divesting five hundred branches during the ERP implementation. This added to the initial complexity of the project. They had previously implemented the Finance and Procurement modules which presented a very high level of complexity that led to an uncontrolled increase in cost. Consequently, the project was suspended. Thereafter, as a consequence of the divestment, new and different employee regulations were introduced into the organisation. This change required an efficient human resources (HR) and payroll system. Therefore, a new ERP implementation for the HR module commenced. The complexity assessment inputs and outputs are outlined in Table 9-6. Scenario A was applied for a high complexity environment.

The output of the complexity assessments is a Kessington's complexity number (KCN) for each activity by complexity type. This determines the overall complexity in each project activity, and is used as a measure for calculating the resource complexity cost.

The inputs of the work breakdown structure and the outputs of the complexity assessment serve as inputs into the dynamic resource complexity costing process. The researcher is aware that the human resources and payroll implementation cost was estimated at £4 million. The preliminary C-REACT WBS cost estimate is £4,150,110.00 at a ± 20% effort variance which is conservative and used as a default for C-REACT. This is used as a margin of error to allow for a relative change in duration in the event of unanticipated circumstances. The variance can be adjusted by the user through a field on the WBS screen, which was provided for this purpose. However, the researcher is satisfied with the preliminary estimate which excludes the results of complexity assessments.

## Table 9-6: Complexity Assessment Inputs and Outputs for Case Study 1

| COMPLEXITY ASSESSMENT INPUTS | | | | COMPLEXITY ASSESSMENT OUTPUTS | | |
|---|---|---|---|---|---|---|
| **Complexity Dimension** | Uncertainty Ranking | Complexity Type | Complexity Type Significance Pairwise Ranking | Uncertainty Score | Complexity Weight | Complexity Level |
| **Business Process Complexity** | 5<br>7<br>3 | Clarity of existing processes | 0.33 | 5 | 0.25 | 5 |
| | | Business process standardisation | 3 | | 0.75 | 5 |
| **Customisation Complexity** | 5<br>7<br>3 | Degree of customisation | 5 | 5 | 0.83 | 5 |
| | | Customisation factors | 0.20 | | 0.17 | 5 |
| **Data Cleansing and Conversion Complexity** | 3<br>7<br>3 | Interface size | 9, 0.33 | 4 | 0.35 | 5 |
| | | Integration of legacy systems | 0.11, 0.2 | | 0.07 | 5 |
| | | Quality of data | 3.03, 5 | | 0.57 | 5 |
| **Organisational Readiness Complexity** | 1<br>5<br>3 | Organisational readiness | 3 | 3 | 0.75 | 5 |
| | | External readiness | 0.33 | | 0.25 | 5 |
| **System Configuration Complexity** | 1<br>1<br>1 | Degree of configuration | 7,3 | 1 | 0.60 | 5 |
| | | Hardware /corporate policies | 0.14, 7 | | 0.28 | 5 |
| | | Test strategy | 0.33, 0.14 | | 0.11 | 5 |
| **Project Control Complexity** | 1<br>1<br>1 | Leadership | 3, 5 | 1 | 0.63 | 5 |
| | | Technical scope | 0.33, 3 | | 0.26 | 5 |
| | | Team attributes | 0.20, 0.33 | | 0.11 | 5 |
| **Internal Resource Participation Complexity** | 1<br>3<br>1 | Culture | 5, 7 | 2 | 0.70 | 5 |
| | | Process owner support | 0.20, 5 | | 0.23 | 5 |
| | | Team members | 0.14, 0.20 | | 0.07 | 5 |
| **User Complexity** | 5<br>3<br>1 | User base | 5, 5 | 3 | 0.59 | 5 |
| | | User training requirement | 0.20, 5 | | 0.33 | 5 |
| | | Trainer attributes | 0.20, 1 | | 0.08 | 5 |

In order to obtain the final cost estimate, Monte Carlo simulation was conducted 1,000 times through agent-based modelling. Figure 9-9 presents the base cost from the simulation with a mean(μ) of £4,138,006 resulting in a difference of £12,104 from the preliminary WBS estimate. In Figure 9-10, the mean(μ) for the resource complexity cost is reported as £4,276,133, which is just over 100% of the base cost.

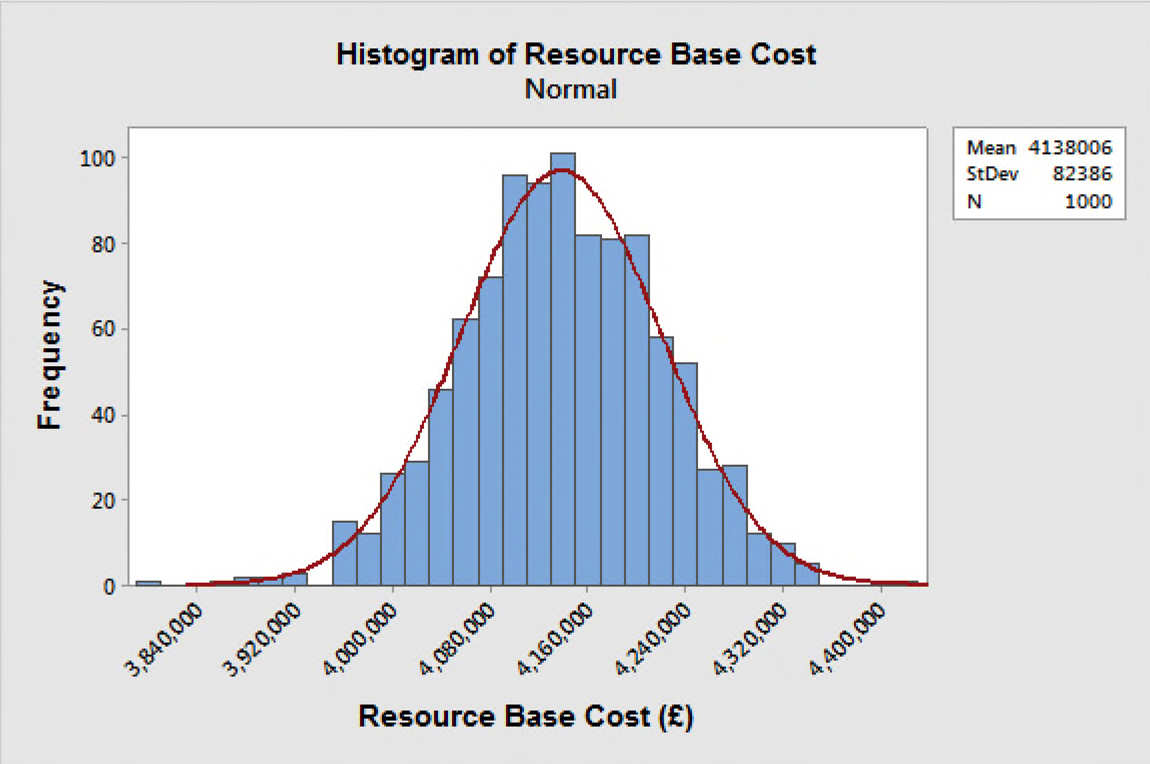



**Figure 9-9:** Resource Base Cost Estimate for Case Study 1

This resource complexity mean is slightly higher than the mean for the resource base cost because the ERP implementation presented very high complexities. As previously stated, the project was undertaken when the bank was acquiring the employees of some of the building societies it had taken over and during its divestment. Furthermore, according to the literature review conducted in this research, the cost of ERP implementations are generally known to cost more than twice as much as the initially estimated amount due to complexities and challenges. The current industrial practice discussed in Chapter 4 also highlights this fact. Figure 9-11 presents the mean(μ) of the resource total cost estimate for this case study as £7,426,451. The standard deviation is £182,045.

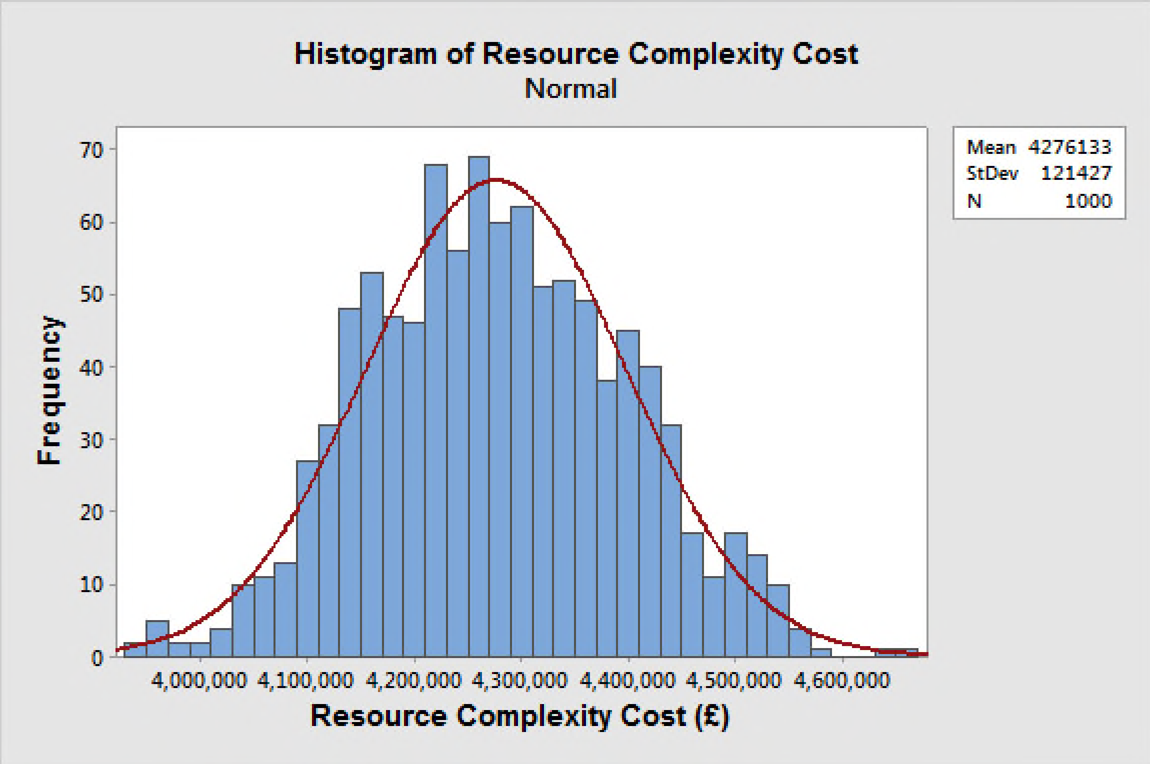



**Figure 9-10:** Resource Complexity Cost Estimate for Case Study 1

The cost estimate is acceptable for this case study as the estimate of the ERP project increased to £6,000,000 shortly before the researcher left the project. At this point, the project had been run for only three months.

Numerous complexities were encountered in the project, as demonstrated in the complexity assessment inputs. These justify the final estimate produced by the C-REACT tool through agent-based modelling and Monte Carlo simulation.

A normal distribution and lognormal distributions were generated in the Monte Carlo simulation. In Figure 9-12, four goodness of fit tests are presented, each at a 95% confidence interval.

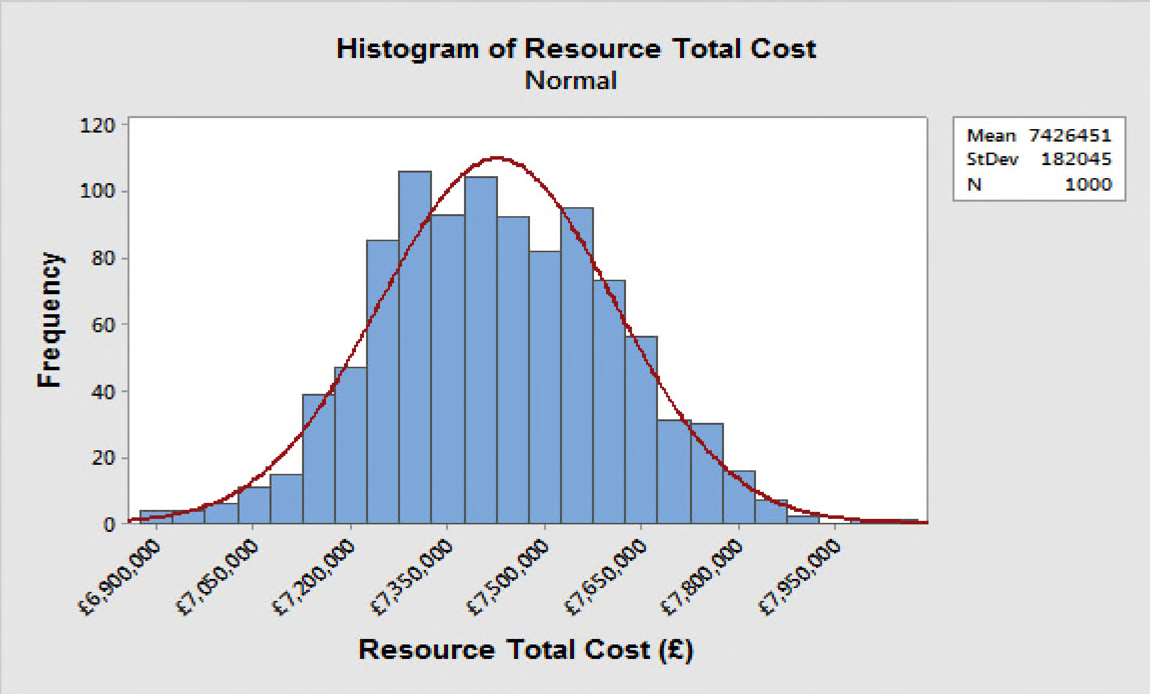



**Figure 9-11:** Resource Total Cost Estimate for Case Study 1

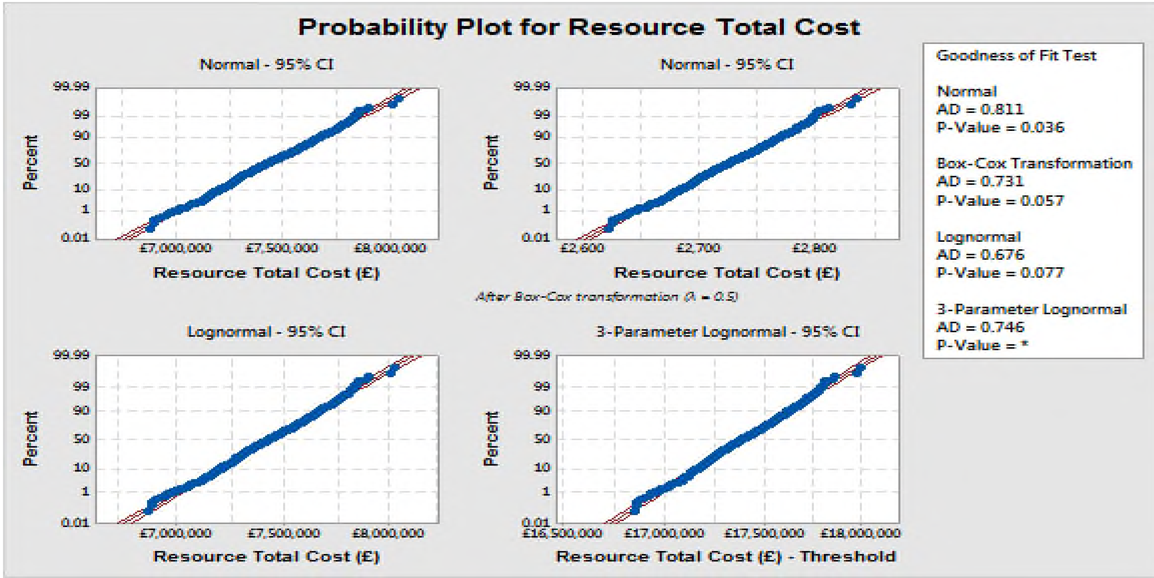



**Figure 9-12:** Goodness of Fit Tests for Resource Total Costs

### 9.4.2 Case Study 2 : ERP in Aerospace

Case study 2 identified a need for a potential ERP solution in November 2013. The key participant from this case study has followed the progress of C-REACT in order to apply it to the estimates for the case study. The potential ERP implementation is intended by an aerospace manufacturing organisation in the UK. The modules planned for implementation are Human Resources and Business Intelligence. Table 9-4 illustrates the work breakdown structure (WBS) inputs. These inputs form the foundation of the resource base cost. The preliminary WBS cost estimate outputs are provided without assessing complexity in Table 9-5. These estimates are initially compared with the original cost for the potential implementation as estimated by the organisation externally of the C-REACT tool. In Table 9-7, the rankings provided by the user in the pairwise comparison for complexity dimensions are highlighted. Additional complexity assessment inputs and associated outputs are presented in Table 9-8.

The preliminary WBS cost estimate for case study 2 is £2,355,005. This amount is acceptable to the case study participant as it is aligned with his initial estimate of £3,300,000 which caters for abstract uncertainties. In comparing the importance of each complexity dimension against another using analytical hierarchy process (AHP) technique, the case study participant highlights that the complexity dimensions which require the most attention are business process complexity, data cleansing and conversion complexity, and organisational readiness complexity. He stressed that several interfaces exist in the case study legacy system, which would require connections into the SAP solution. In Table 9-8, the importance of the complexity types for each of the dimensions, the uncertainty rankings for each complexity dimension, the complexity weight and complexity level for each complexity type are presented. Some of these attributes and inputs and the others are outputs of the tool.

**Table 9-7:** Complexity Dimension Pairwise Comparisons for Case Study 2

| **Complexity Dimension** | Business Process Complexity | Customisation Complexity | Data Cleansing and Conversion Complexity | Organisational Readiness Complexity | System Configuration Complexity | Project Control Complexity | Internal Resource Participation Complexity | User Complexity |
|---|---|---|---|---|---|---|---|---|
| Business Process Complexity | 1.00 | 5.00 | 1.00 | 3.00 | 5.00 | 5.00 | 7.00 | 7.00 |
| Customisation Complexity | 0.20 | 1.00 | 0.33 | 0.33 | 1.00 | 0.33 | 0.33 | 1.00 |
| Data Cleansing and Conversion Complexity | 1.00 | 3.00 | 1.00 | 3.00 | 3.00 | 7.00 | 7.00 | 7.00 |
| Organisational Readiness Complexity | 0.33 | 3.00 | 0.33 | 1.00 | 5.00 | 5.00 | 5.00 | 7.00 |
| System Configuration Complexity | 0.20 | 1.00 | 0.33 | 0.20 | 1.00 | 3.00 | 1.00 | 5.00 |
| Project Control Complexity | 0.20 | 3.00 | 0.14 | 0.20 | 0.33 | 1.00 | 3.00 | 1.00 |
| Module Complexity | 0.14 | 3.00 | 0.14 | 0.20 | 1.00 | 0.33 | 1.00 | 0.11 |
| External Resource Complexity | 0.14 | 1.00 | 0.14 | 0.14 | 0.20 | 1.00 | 9.00 | 1.00 |

In the complexity assessment, the complexity types with high complexity levels are clarity of existing processes, customisation factors, organisational readiness, external readiness, leadership, technical scope, team attributes, inter-module integration and hardware/corporate policies to assess the interfaces which will be connected to the SAP system. Two scenarios based on the complexity types were conducted.

**Table 9-8:** Complexity Assessment Inputs and Outputs for Case Study 2

| **COMPLEXITY ASSESSMENT INPUTS** | | | | **COMPLEXITY ASSESSMENT OUTPUTS** | | |
|---|---|---|---|---|---|---|
| **Complexity Dimension** | Uncertainty Ranking | Complexity Type | Complexity Type Significance Pairwise Ranking | Uncertainty Score | Complexity Weight | Complexity Level |
| **Business Process Complexity** | 3 1 5 | Clarity of existing processes | 9.0; 5.0 | 3 | 0.90 | 4 |
| | | Business process standardisation | 0.11; 0.2 | | 0.10 | 3 |
| **Customisation Complexity** | 5 7 3 | Degree of customisation | 5 | 3 | 0.83 | 3 |
| | | Customisation factors | 0.20 | | 0.17 | 5 |
| **Data Cleansing and Conversion Complexity** | 1 3 5 | Interface size | 3, 5; 3, 0.2 | 4 | 0.57 | 4 |
| | | Integration of legacy systems | 0.33, 9; 0.33, 0.14 | | 0.35 | 3 |
| | | Quality of data | 0.20, 0.11; 5, 7 | | 0.07 | 3 |
| **Organisational Readiness Complexity** | 1 1 3 | Organisational readiness | 3 | 2 | 0.75 | 4 |
| | | External readiness | 0.33 | | 0.25 | 4 |
| **System Configuration Complexity** | 1 3 5 | Degree of configuration | 5,3 | 3 | 0.60 | 1 |
| | | Hardware /corporate policies | 0.20, 5 | | 0.28 | 4 |
| | | Test strategy | 0.33, 0.20 | | 0.12 | 5 |
| **Project Control Complexity** | 3 3 5 | Leadership | 3, 5 | 4 | 0.63 | 5 |
| | | Technical scope | 0.33, 3 | | 0.26 | 5 |
| | | Team attributes | 0.20, 0.33 | | 0.11 | 5 |
| **Module Complexity** | 1 1 3 | Module Maturity | 5 | 2 | 0.83 | 3 |
| | | Inter-Module Integration | 0.20 | | 0.17 | 4 |
| **External Resource Complexity** | 3 3 3 | Level of Experience | 5, 9 | 3 | 0.61 | 3 |
| | | Onshore/ Offshore/ Rightshore | 0.20, 7 | | 0.34 | 3 |
| | | Total Team Size | 0.11, 0.14 | | 0.05 | 3 |

The complexity type pairwise significance ranking with semi colons (for instance, clarity of existing process) is an indication of values used in two different scenarios.  The value preceding the semi colon was used in the first scenario, and the value succeeding the semi colon was used in the second scenario.

Upon running the Monte Carlo simulation for estimating the resource base cost through 1000 runs, a normal distribution produces a mean($\mu$) of £2,330,457 for the resource base cost, as presented in Figure 9-13.  This figure is close to the WBS preliminary estimate and is acceptable to the case study participant as the complexity assessment is not incorporated in this figure.  A standard deviation($\sigma$) of £52,236 is produced for the resource base cost.  The Monte Carlo distribution produces a resource complexity mean($\mu$) of £2,545,333 which is higher than the estimated resource base cost.  The participant is not satisfied with this figure as it is higher than he anticipated.  However, numerous complexities have been assessed for the case study and each one has a KCN which is introduced into one or more project activities.  The KCNs accumulate and result in the mean that has been presented in Figure 9-14.  A KCN represents a classification of complexity in a project activity.  It demonstrates a presence of complexity and serves as a complexity measure.

Literature review suggests that some of the ERP implementation cost overruns can double the initial estimate due to unanticipated challenges and poor cost estimation (Babock, 2011; Kanaracus, 2011; Momoh *et al*., 2010; Ehie *et al*., 2005).  Montalbano (2010) reports a SAP implementation which was initially estimated at $14.2 million and ended up costing $47.4 million which is triple the estimate. In Figure 9-15, the resource total mean($\mu$) for case study 2 is estimated as £4,359,761 with a standard deviation($\sigma$) of £104,421.  In Figure 9-16, the goodness of fit tests for the resource total cost indicates a 95% confidence interval for each of the four tests produced.  The researcher demonstrated these figures to the case study participant in order to provide them with the confidence that the costs are normally distributed and that the goodness of fit tests indicate that the data fits the distributions.

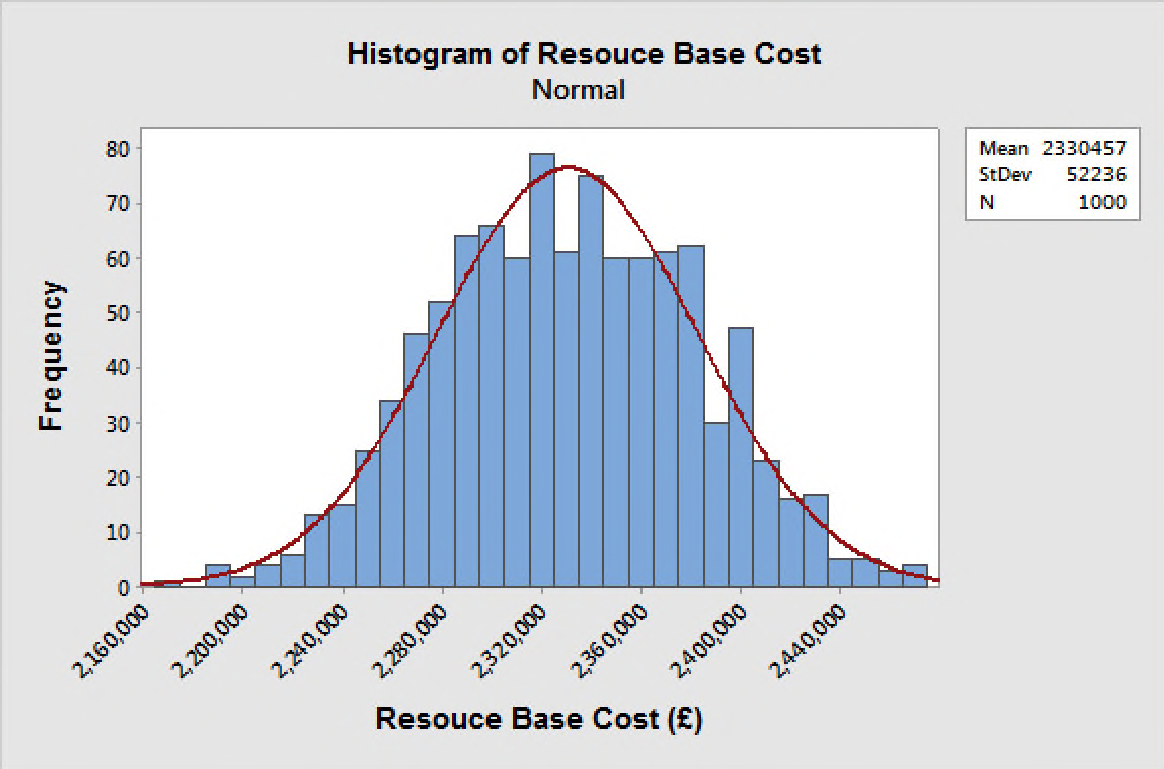



**Figure 9-13:** Resource Base Cost Estimate for Case Study 2

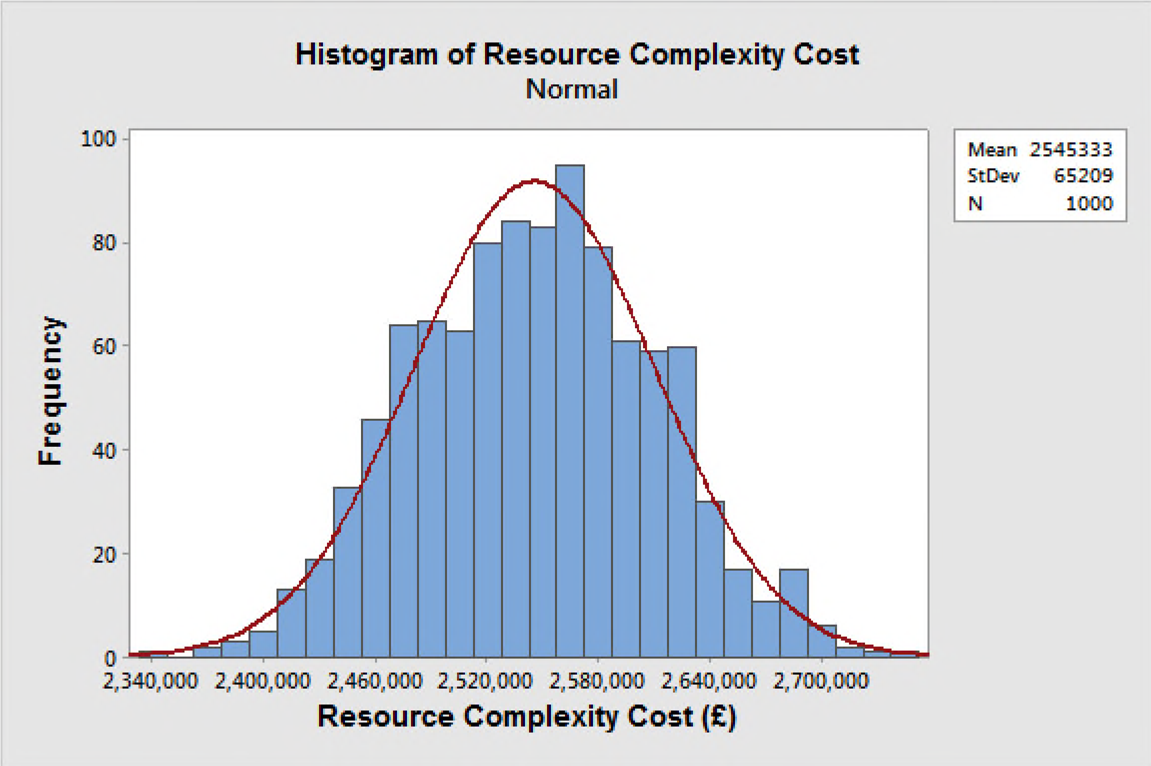



**Figure 9-14:** Resource Complexity Cost Estimate for Case Study 2

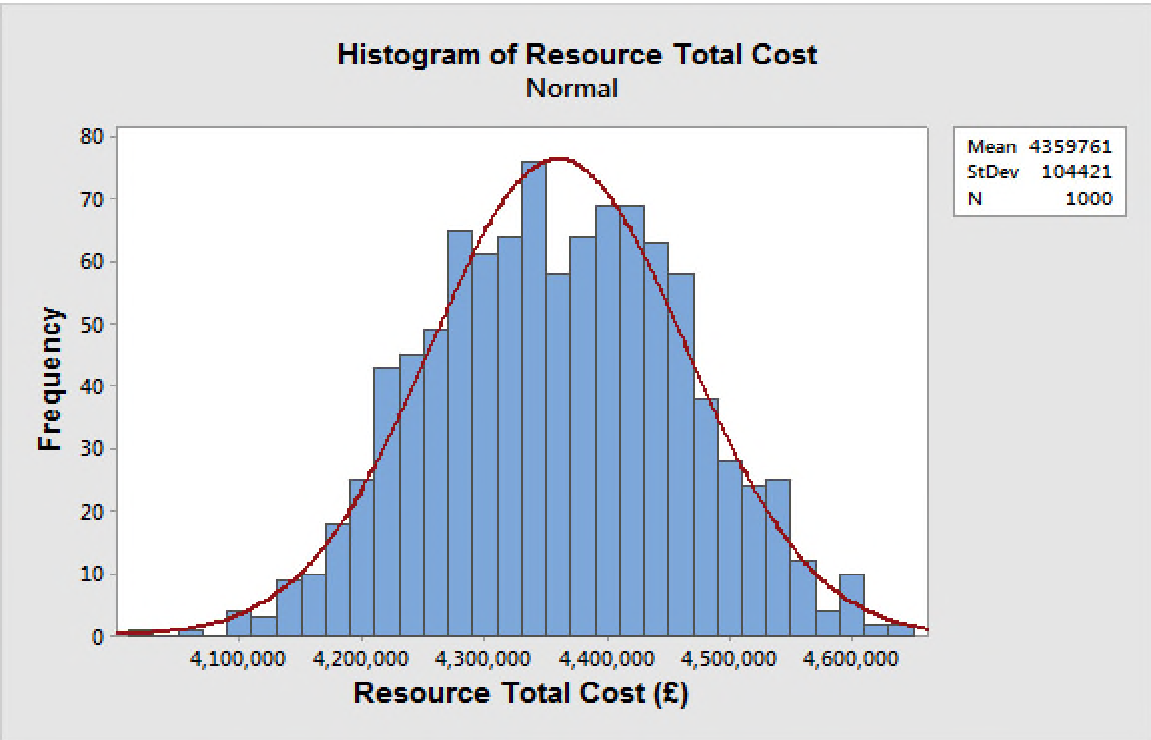



**Figure 9-15:** Resource Total Cost Estimate for Case Study 2

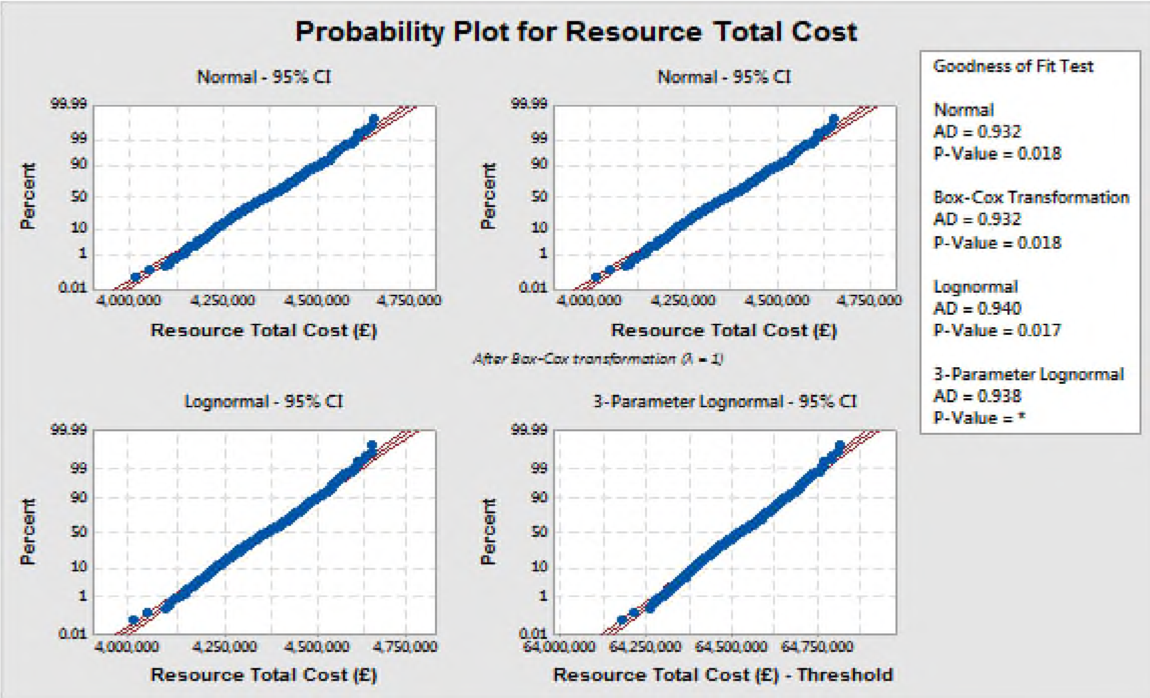



**Figure 9-16:** Goodness of Fit for Resource Total Cost Estimate

The case study participant reviewed the complexity assessment in an effort to detect the cause of the high cost. He observed that his initial ranking for the complexity types in business process complexity and data cleansing and conversion complexity did not reflect an absolute picture of the project. Hence, he changed the rankings as follows:

- clarity of existing process from 9 to 5 which automatically changed business process standardisation from 0.11 to 0.20
- interface size from 3 and 5 to 3 and 0.2
- integration of legacy systems from 0.33 and 9 to 0.33 and 0.14
- quality of data from 0.20 and 0.11 to 5 and 7

These changes constituted a second scenario. The participant was interested in the impact which this change will have on the KCN in the different activities. However, the change was marginal. The initial KCN was 0.51 and was recalculated as 0.48 as a result of the change to the AHP rankings. The resource complexity costing module of C-REACT was rerun, and the change in cost was insignificant. Consequently, the participant reviewed the cost for each resource to identify which one generated the highest complexity cost. He discovered that the functional consultant (FCON) cost contributed to the majority of the complexity cost at £1,190,326.988 as illustrated in Figure 9-17. The technical consultant (TCON) contributed to the next highest cost at £692,397.346. The functional consultant is hired at a rate of £750 a day and there are six functional consultants on the project. Therefore, their base cost is quite high. Consequently, additions of KCN to the base cost will increase it substantially. This increase is exponential because the functional consultant works in 18 activities and KCNs exist in 9 of these activities. Each activity constitutes a number of complexities, each represented by a KCN. Each KCN is converted to a percentage and added to the base cost.

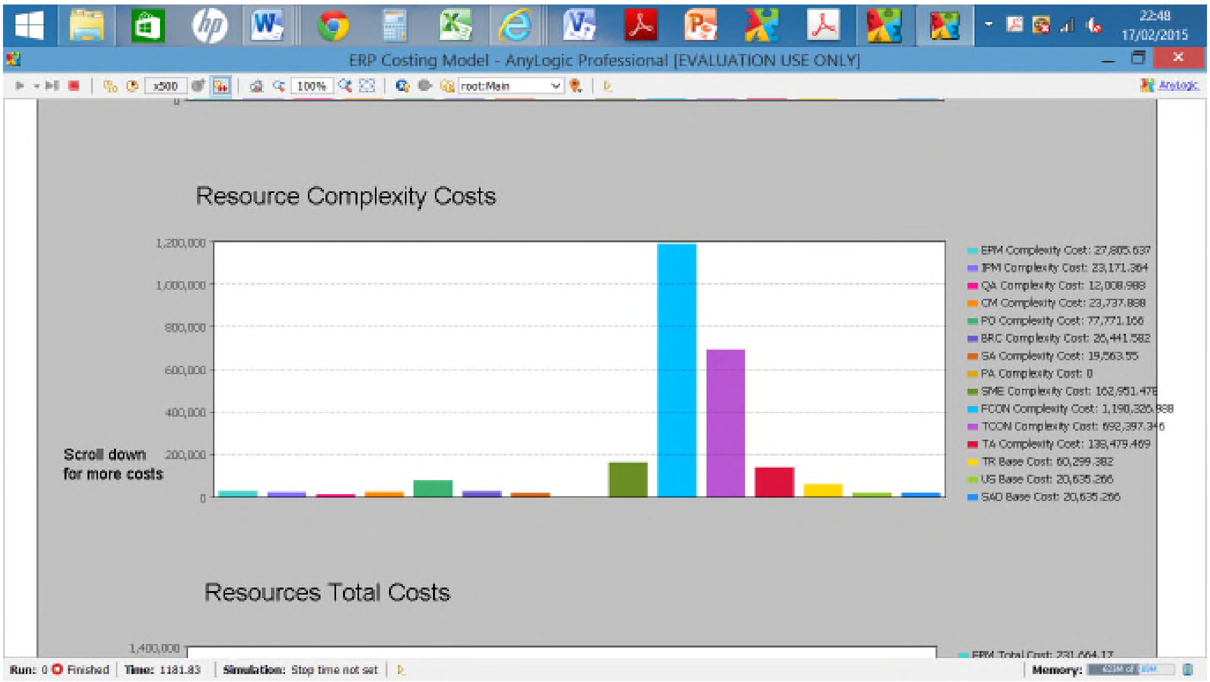



**Figure 9-17:** Resource Complexity Cost for Case Study 2

Once the participant had detected the highest complexity costs, he accepted the result of the complexity assessment. He mentioned that the WBS Complexity Matrix is an excellent report and should be used by all project managers because it clearly demonstrates where the complexities exist in the project. This matrix aids in justifying the complexity cost. It enabled him to immediately plan toward controlling and reducing the complexity even before the project commences. He advised that he would keep the senior functional consultants whom are onshore, on the analyse business process activity to design the business processes which would be configured. Thereafter, the majority of these consultants will be replaced with offshore consultants for the configuration of the system and related activities. This would substantially reduce the complexity cost for the consultants and would be more aligned with his initial estimate. This resource model which he would adopt is presented in this thesis for future research work as an addition to a future version of this model.

### 9.4.3 Case Study 3 : ERP in Electronics

Case study 3 is based on a SAP implementation which ended in June 2012. The ERP implementation was undertaken by a global electronics manufacturing organisation. Their previous implementation was a large one, which spanned four years. The modules implemented were Finance, Procurement, Production and Sales. They are in the process of implementing a new module, Human Resources (HR). Hence they require a complexity cost estimating tool. The participant of the case study who was the IT director from the organisation conceded that their initial implementation was extremely complex. Therefore, it is imperative that they take advantage of a tool like C-REACT to validate its applicability and suitability in cost estimating by comparing its estimate with that of their previous implementation.

In Table 9-9, the additional complexity assessment inputs and associated outputs are presented. The cost estimates were calculated in euros, which is the project currency. The preliminary cost estimate which was produced by the WBS was €11,038, 050 without user costs and without assessed complexity. This figure was immediately accepted by the participant. Their initial estimate with contingency was €15 million. This contingency accounted for uncertainty in the event of unanticipated complexity.

The IT project director of the electronics company advised that they had hired the best resources in the ERP market at the time of the implementation. Consequently, their rates were very high. Additionally, a consultancy was employed to play the role of subject matter experts and technical analysts, which would typically be played by internal staff. This also involved training for these resources which was provided by the internal staff. The training was required in order to enable the external resources to convey the business requirements to the ERP consultants. This attracted a very high level of complexity.

In the AHP rankings, the complexity types which were scored quite high compared to the others are business process standardisation (0.75), customisation factors (0.75), interface sizes (0.62), external readiness (0.75), test strategy (0.55), leadership (0.63), level of experience (0.69), and regulation (0.90). Business process standardisation was ranked quite high because the implementation was global, and involved harmonising the processes of all the companies across the world. The customisation factors complexity was also ranked high because of the global nature of the implementation. Customisation of the processes in one country affected the processes in the implementation of the other countries. Regulation was scored 90% because of the local legislation of each country in relation to tax changes during implementation. In the process of scoring the complexities according to their level of complexity, the participant selected the first scenario for a very high complexity environment with highly skilled resources.

Once the Monte Carlo simulation for estimating the resource base cost was run 1,000 times, a normal distribution produced a mean($\mu$) of €11,010,627 as illustrated in Figure 9-18. This amount is close to the WBS preliminary estimate of €11,038, 050 and is acceptable to the case study participant in the absence of complexity assessment. A standard deviation of €240,659 is produced for the resource base cost. The Monte Carlo simulation produced a resource complexity mean($\mu$) of €10,528,257 which is almost twice the estimate of the resource base cost as indicated in Figure 9-19. The mean for the total resource cost estimate is produced as €21,538,884, which is illustrated in Figure 9-20. This is higher than the original implementation estimate by €6,538,884. However, the participant concedes that even though complexity is accounted for in the initial estimate, it is done on an abstract level and without any structured complexity assessment. Having seen the KCNs which were attached to the complexities of his case study, he accepted the estimate produced by C-REACT.

In Figure 9-21, the goodness of fit tests for the resource total cost indicates a 95% confidence interval for each of the four tests produced. The researcher demonstrated these figures to the case study participant in order to provide them with the confidence that the costs are normally distributed and the goodness of fit tests indicate that the data fits the distributions.

**Table 9-9:** Complexity Assessment Inputs and Outputs

| **COMPLEXITY ASSESSMENT INPUTS** | | | | **COMPLEXITY ASSESSMENT OUTPUTS** | | |
|---|---|---|---|---|---|---|
| **Complexity Dimension** | Uncertainty Ranking | Complexity Type | Complexity Type Significance Pairwise Ranking | Uncertainty Score | Complexity Weight | Complexity Level |
| **Business Process Complexity** | 3<br>1<br>1 | Clarity of existing processes | 0.33 | 2 | 0.25 | 5 |
| | | Business process standardisation | 3 | | 0.75 | 5 |
| **Customisation Complexity** | 1<br>3<br>3 | Degree of customisation | 0.33 | 2 | 0.25 | 5 |
| | | Customisation factors | 3 | | 0.75 | 5 |
| **Data Cleansing and Conversion Complexity** | 3<br>3<br>3 | Interface size | 3, 5 | 3 | 0.62 | 5 |
| | | Integration of legacy systems | 0.33, 0.33 | | 0.14 | 5 |
| | | Quality of data | 0.20, 3 | | 0.24 | 5 |
| **Organisational Readiness Complexity** | 1<br>3<br>3 | Organisational readiness | 0.33 | 3 | 0.25 | 5 |
| | | External readiness | 3 | | 0.75 | 5 |
| **System Configuration Complexity** | 3<br>3<br>3 | Degree of configuration | 5, 0.33 | 3 | 0.33 | 5 |
| | | Hardware /corporate policies | 0.20, 0.33 | | 0.12 | 5 |
| | | Test strategy | 3, 3 | | 0.55 | 5 |
| **Project Control Complexity** | 5<br>3<br>3 | Leadership | 5, 3 | 3 | 0.63 | 5 |
| | | Technical scope | 0.20, 0.33 | | 0.11 | 5 |
| | | Team attributes | 0.33, 3 | | 0.26 | 5 |
| **External Resource Complexity** | 3<br>3<br>5 | Level of Experience | 9,3 | 4 | 0.69 | 1 |
| | | Onshore/ Offshore/ Rightshore | 0.11, 0.33 | | 0.08 | 5 |
| | | Total Team Size | 0.33, 3 | | 0.23 | 5 |
| **External Factors Complexity** | 3<br>3<br>3 | Regulation | 9 | 3 | 0.90 | 5 |
| | | Exchange Rate | 0.11 | | 0.10 | 5 |

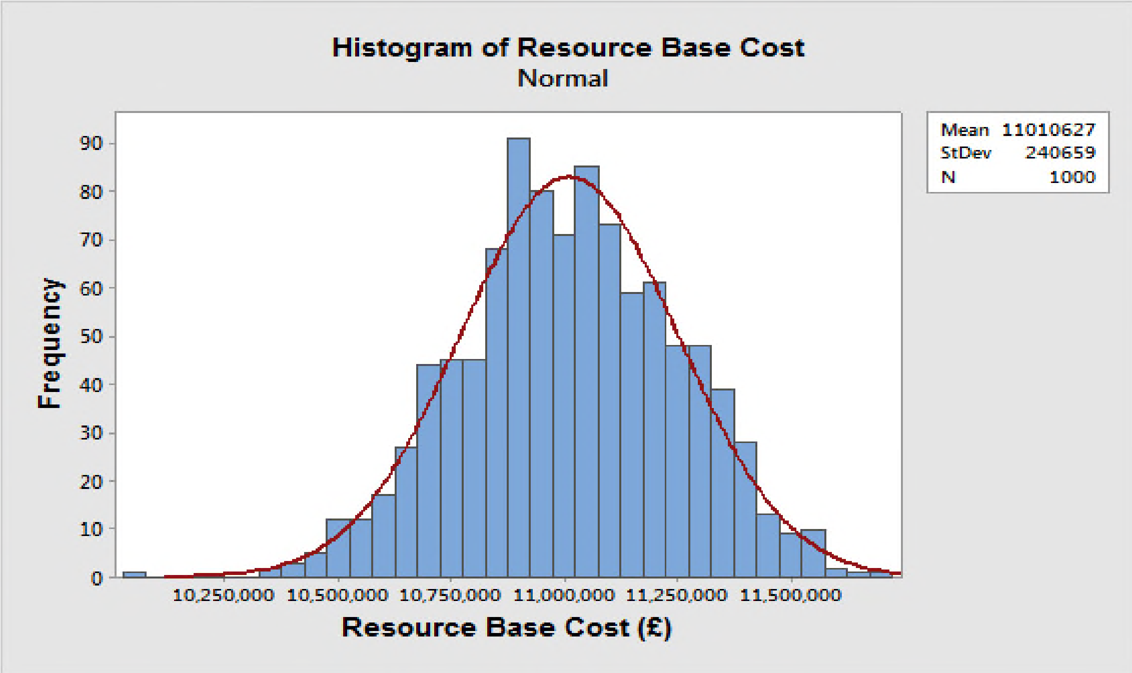



**Figure 9-18:** Resource Base Cost Estimate for Case Study 3

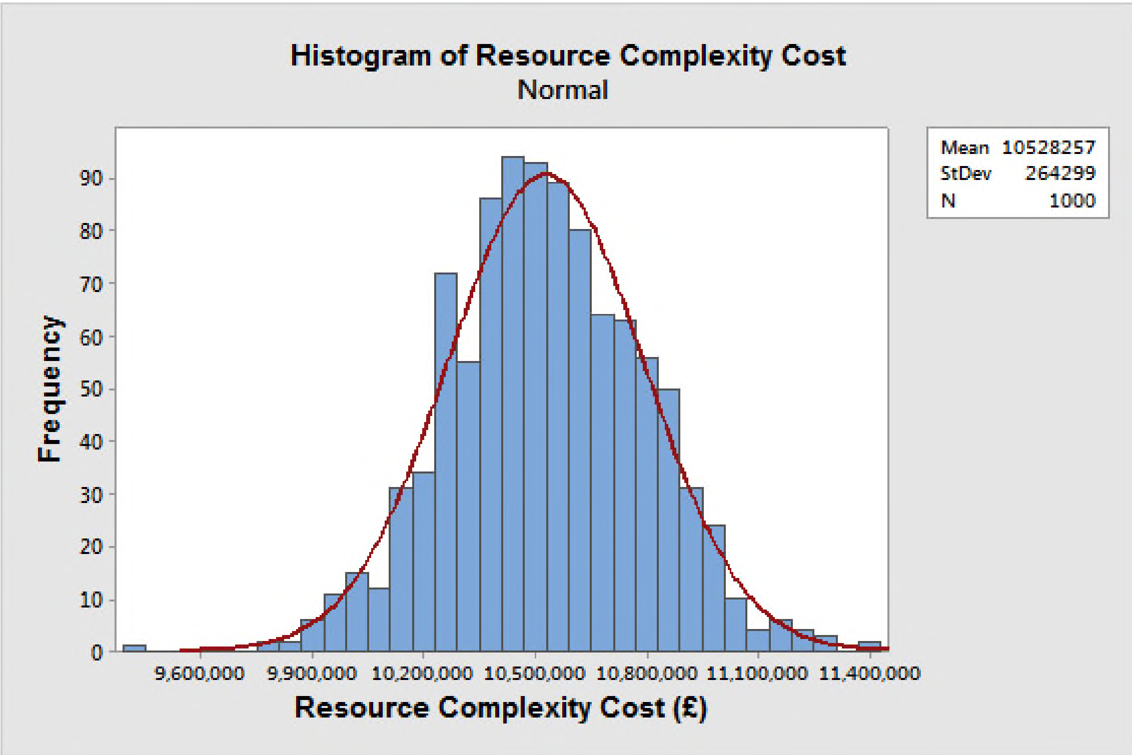



**Figure 9-19:** Resource Complexity Cost Estimate - Case Study 3

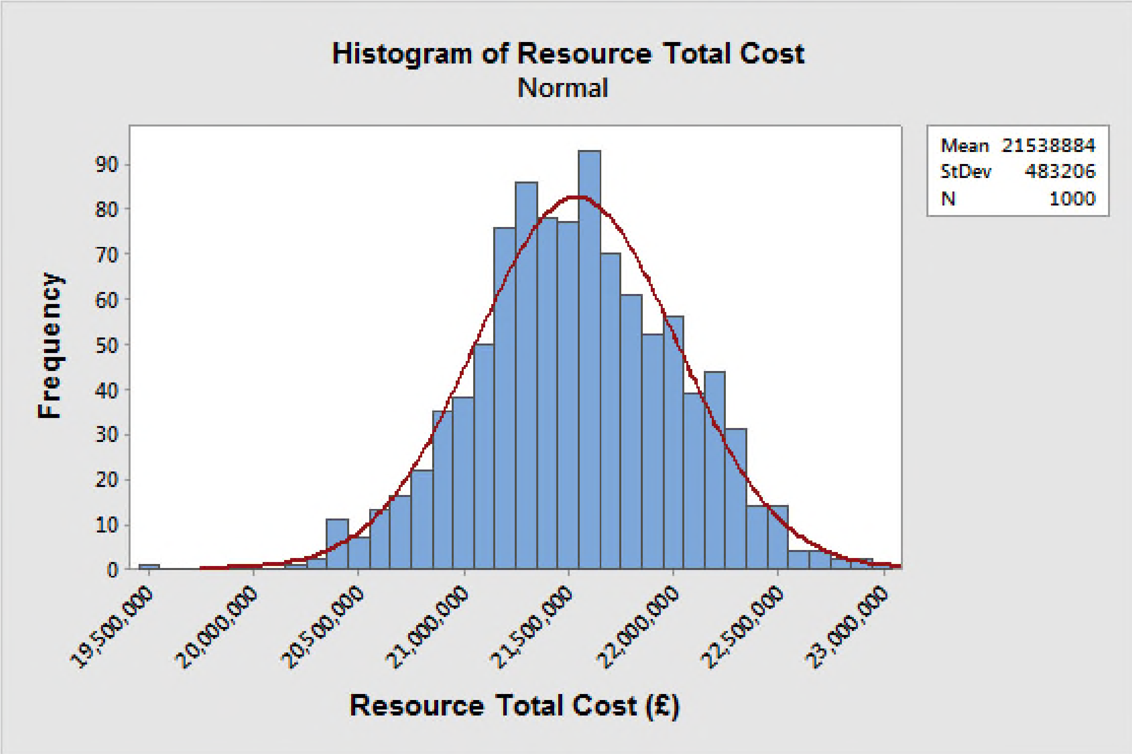



**Figure 9-20:** Resource Total Cost Estimate for Case Study 3

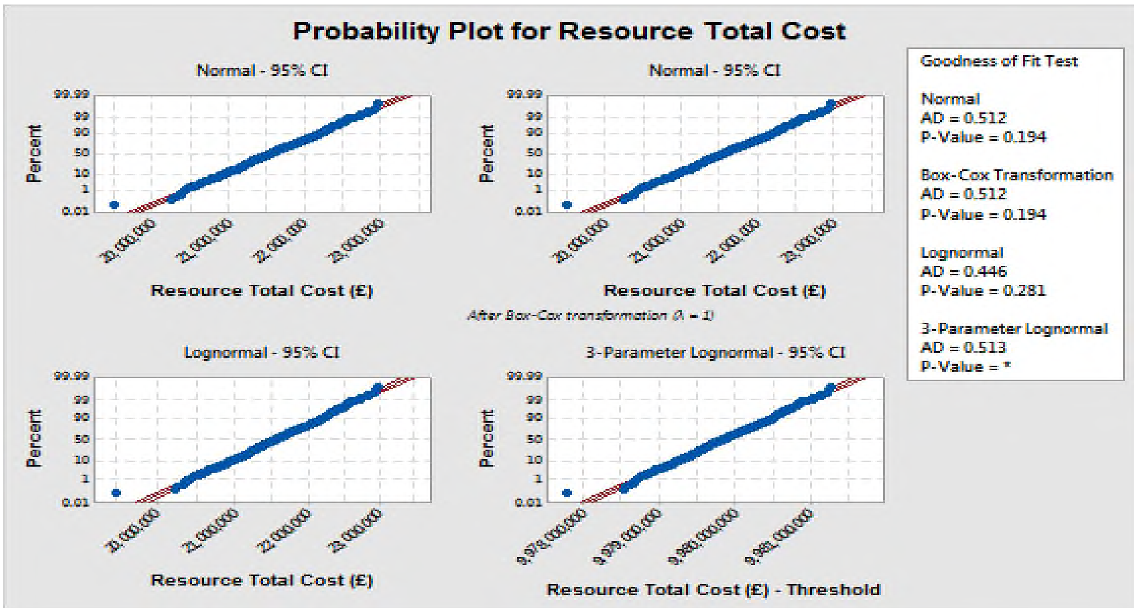



**Figure 9-21:** Probability Plot for Resource Total Cost Estimate - Case Study 3

## 9.5 Tool Validation through Experts' Opinion

C-REACT was also validated by experts in the field of enterprise resource planning (ERP). As the tool constitutes a work breakdown structure for project scheduling and resourcing, complexity assessment and cost estimation, experts with experience in these different areas were engaged in the tool validation process. The experts cover the roles of ERP project manager, I.T. manager, ERP functional consultant and ERP technical consultant. The project managers are also cost estimation experts and have a wide range of industrial experience in ERP implementations. This diversity was fulfilled in order to ensure a breadth and depth of knowledge and experience in the relevant areas to be validated. Additionally, it produced a platform for expressing different perspectives and opinions of the tool.

A total number of eight face-to-face interviews and WebEx teleconferences, each lasting two hours were conducted in the validation process. The details of the experts involved in the tool validation are provided in Table 9-1.

### 9.5.1 Expert Opinion Analysis

Analysis and comparison of experts' opinions of the tool was based on the responses which the experts provided in their questionnaires during validation. The results are presented as follows:

- **Logic:**

The responses to the question "How logical are the complexity concepts and features in the framework", as well as the scale used to capture them in the questionnaire are illustrated in Table 9-10.

**Table 9-10:** How logical are the complexity concepts and features in the framework? - Ratings

| 1 | 2 | 3 | 4 | 5 | 6 | **7** | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

| **Experts** | **Exp 11** | **Exp 12** | **Exp 13** | **Exp 17** | **Exp 23** | **Exp 24** | **Exp 25** | **Exp 28** | **AVG.** |
|---|---|---|---|---|---|---|---|---|---|
| **Scores** | 10 | 10 | 10 | 10 | 7 | 8 | 9 | 7 | 8.87 |

All eight experts agreed that the development of a framework to support complexity assessment is completely valid. However, Expert 28 identified a minor deficiency. He advised that the way to compare complexity drivers might be open to different interpretations per respondent. Also, Expert 24 recommended better visibility of some of the notes on the screens.

The responses to the question “Is the framework suitable for the needs identification stage of the whole life cycle?”, as well as the scale used to capture them in the questionnaire are illustrated in Table 9-11.

**Table 9-11:** Is the framework suitable for the needs identification stage of the whole life cycle?- Ratings

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

| **Experts** | **Exp 11** | **Exp 12** | **Exp 13** | **Exp 17** | **Exp 23** | **Exp 24** | **Exp 25** | **Exp 28** | **AVG.** |
|---|---|---|---|---|---|---|---|---|---|
| **Scores** | 9 | 10 | 10 | 10 | 8 | 10 | 10 | 7 | 9.25 |

All the experts agreed that the C-REACT framework is very suitable for the needs identification stage of an ERP whole life cycle. There were no deficiencies highlighted.

- **Generalisability:**

The eight experts agree that the C-REACT framework is generalizable within their respective industries. Although Expert 28 cautioned that he is not in a position to fully agree on the tool's generalizability as he has not seen the data input by the other respondents, and is uncertain as to whether they apply to his industry. However, he compared the complexity factors in the tool with those of his company's and observed several similarities. Expert 25 advised that based on his experience, he observed that the tool contains complexity types and cost drivers which are quite generic. Therefore, they can be used in the manufacturing and aerospace industries. Expert 17 expressed that the tool is generalizable in his industry as most ERP implementations in his industry have experienced the same complexities. However, he recommends that a study be conducted on aerospace-specific complexities and cost drivers which should be incorporated in the tool and tailored towards the aerospace industry. Expert 12 and Expert 13 concur that the tool is generalizable within SAP consulting as the companies in this industry have experienced similar challenges. Therefore, the SAP consultancies can apply the tool to different customers. Expert 24 suggests that the work breakdown structure in C-REACT is not completely aligned with the project life cycle employed in his organisation. However, he is not equipped to suggest the same about the methodologies used in similar organisations. This comment is understandable because different companies normally adopt and apply their own specific methodologies to their projects.

- **Benefits of using the Framework:**

Expert 29 emphasises that C-REACT is a tool which is direly required in ERP implementations to enable a structure and process in the assessment of complexities and their incorporation in project costs. This allows organisations to justify their ERP project estimates with a reasonable level of confidence. He also conveyed that complexities experienced by resources can be identified by using C-REACT, and controlled outside of the tool even before the implementation begins. This would reduce the estimated implementation cost. Expert 25 concurs with Expert 29 by expressing that the project team would have a good idea of the potential cost of an ERP implementation, whilst having a detailed understanding of the complexities which might occur. Expert 17 asserts that knowledge of the complexities identified for a potential ERP implementation will enable the needs identification team to run different "what-if" scenarios based on the presentations of complexities possessing different scales and levels. He expresses that the outcomes of these scenario analysis will allow for control and reduction of ERP complexities and costs. Expert 28 advises that C-REACT would provide a qualitative view on complexity impacts. Expert 24 suggests that the tool will benefit the needs identification team by ensuring that all items of complexity are understood and discussed by the relevant stakeholders.

- **Limitations of the Framework:**

Expert 28 cautions that he the comparison of complexity factors in the tool is not easy, and as a result, could be open to multiple interpretations. Expert 12 discusses the tool from a consulting perspective and highlights that as C-REACT possesses depth, ERP functional consultants would not be experienced enough to use it. However, they should be equipped to utilise the tool in order to enable their understanding of the potential complexities which they may face. This would prepare them for any forthcoming complexities a project may present. Expert 13 agrees with the analysis of Expert 12. Both experts also emphasise that as project managers with ERP experience are very likely to be the lead users of C-REACT, they might not be in the best position to weigh some of the complexities accurately. This is because their management experience does not always allow them a complete understanding of the complexities encountered by functional and technical resources. Therefore, both experts strongly recommend that senior ERP functional and technical consultants are allowed to use the tool for comprehensive complexity assessment and costing. Expert 24 conveys that the tool requires more flexibility in creating the work breakdown structure. He also advises that the tool should enable automatic verification and validation of inputs in order to reduce the guesswork by the user. Expert 24 further emphasises that the tool should provide more detail in what is required for WBS inputs in order to ensure more accurate inputs. Expert 17 expresses that using the manual score option in assessing the uncertainty of complexity estimates does not present validated scores. This will pose challenges for the user, as they are allowed to input any value. He advises that the values should be restricted to a range of 1 to 7 for consistency and alignment with the NUSAP scores. Expert 17 also cautions that the maintenance of the tool may be cumbersome, thereby requiring an agreement to be reached about who will maintain it for its user. He further stresses that the default values in the work breakdown structure are unusually high, and should be reduced where possible. Additionally, he advises that the costing of users in the WBS may be misleading as users are typically employees of the organisations running the ERP projects, and are usually not included in project estimates because they are not project team members. Therefore, he suggested that user costing is presented as an option for the user.

- **Usability of the Tool:**

All eight experts agree that the tool is easy to use. They concur that the layout is very good, the colour use across the tool is uniform with no surprises, the navigation is good, the tool is sophisticated, it is flexible enough to accept alternatives already implemented in it, and most of the terminologies are clear. Expert 25 cautions that the tool should not be too flexible, when asked about his opinion on the tool's flexibility. His reason for this is that flexibility could cause a lack of control and manageability of the relevant inputs. However, he stresses that the tool asks all the right questions in one place instead of using different tools to achieve one goal, which his company currently practices. Expert 28 emphasises that with some assumptions, the tool allows the user to build models for the ERP implementation at hand.

**Strongest Features in the Tool**

Expert 17 highlighted that one of the strongest features of the tool is in allowing the identification and assessment of pre-defined and validated complexities which are kept to a manageable size. These features allow him to observe that the importance of one complexity over another is crucial for costing. Expert 25 describes one of the tool's strongest features as the capability to provide five mandatory complexity dimensions and three complexity dimensions selected from the remaining six dimensions. He highlights this as a superb feature because it allows the user to run different scenarios based on the different inputs at different times. The five mandatory dimensions also enable different organisations (ERP adopters, ERP consultancies and ERP vendors) working on the same projects to operate from the same platform upon which to base their estimates. Expert 12 and Expert 13 discuss the strongest feature of the tool as the pre-specification of all eleven complexities instead of allowing the user to input their own. They both advise that another strong feature is providing the capability to identify the areas in the WBS where these complexities occur. Expert 25 further advises that providing a user guide as part of the tool is an excellent functionality. He also likes the capability of providing the user with options. Expert 28 outlines the strongest features of the tool as the work breakdown structure and sensitivity analysis on complexity factors.

**Weakest Features in the Tool**

Expert 17 cautions that the manual scoring of uncertainty for complexity estimates, does not have an explanation box like that for the NUSAP pedigree scoring. A box should be provided to explain each score. He also asserts that in the WBS complexity matrix, there is no distinction between the least complex and the most complex activities. Therefore, colour coding should be implemented to provide this distinction as it will provide organisations with an instant view of where to focus their efforts. According to Expert 17, the user is unable to distinguish between input and output fields in the WBS. This should be enabled with colour coding for differentiation. Expert 25 highlights that the user is unable to distinguish between default values and their own values upon changing the former. Therefore, he suggests colour coding to be used to address this limitation. He mentions that the tool does not provide validation in the background which manages the relationships of the direct influence cost estimates with the WBS activities which they relate to. Expert 28 highlights that the tool is less flexible to adapt to context specific situation of the organisation for which the tool is applied. Expert 12 and Expert 13 both agree that one of the weakest features of the framework is the clutter in the direct influence cost driver screen.

- **Framework Assessment:**

The experts were requested to assess the completeness and suitability of the framework for the following questions:

i. The dimensions and types of complexity
ii. The work breakdown structure activities and resources
iii. Applying a three-point estimate in specifying the duration for each activity
iv. Calculating an uncertainty score for complexity estimates using the NUSAP criteria
v. Applying the analytical hierarchy processing (AHP) technique to derive weights for complexities
vi. Deriving complexity levels using pre-defined criteria
vii. Calculating the final complexity score known as Kessington's Complexity Number by multiplying the complexity weight by the complexity level

The responses to question (i) and the scale which was used to capture them in the questionnaire are illustrated in Table 9-12.

**Table 9-12:** Assess the Completeness/Suitability of the Framework for the Dimensions and Types of Complexities - Ratings

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Incomprehensive | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Comprehensive |

| **Experts** | **Exp 11** | **Exp 12** | **Exp 13** | **Exp 17** | **Exp 23** | **Exp 24** | **Exp 25** | **Exp 28** | **AVG.** |
|---|---|---|---|---|---|---|---|---|---|
| **Scores** | 9 | 9 | 9 | 10 | 7 | 10 | 10 | 8 | 9 |

The responses to question (ii) and the scale which was used to capture them in the questionnaire are illustrated in Table 9-13.

**Table 9-13:** Assess the Completeness/Suitability of the Framework for Work Breakdown Activities and Resources - Ratings

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Incomprehensive | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Comprehensive |

| **Experts** | **Exp 11** | **Exp 12** | **Exp 13** | **Exp 17** | **Exp 23** | **Exp 24** | **Exp 25** | **Exp 28** | **AVG.** |
|---|---|---|---|---|---|---|---|---|---|
| **Scores** | 10 | - | - | 10 | 8 | 7 | 8 | 7 | 8.3 |

Expert 24 asserts that the work breakdown structure did not entirely relate to the standard project life cycle adopted by his organisation. Expert 25 cautions that the work breakdown structure is not generalizable in the aerospace and defence industry, as it does not contain project resources that are specific to this industry.

The responses to question (iii) and the scale which was used to capture them in the questionnaire are illustrated in Table 9-14.

**Table 9-14:** Assess the Completeness/Suitability of the Framework for Applying a Three-Point Estimate in Specifying the Duration for Each Activity – Ratings

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

| Experts | Exp 11 | Exp 12 | Exp 13 | Exp 17 | Exp 23 | Exp 24 | Exp 25 | Exp 28 | AVG. |
|---|---|---|---|---|---|---|---|---|---|
| **Scores** | 10 | - | - | 10 | 7 | - | 10 | 10 | 9.4 |

The responses to question (iv) and the scale which was used to capture them in the questionnaire are illustrated in Table 9-15.

**Table 9-15:** Assess the Completeness/Suitability of the Framework for Calculating the Uncertainty Score by Averaging the Scores across the three NUSAP Criteria- Ratings

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Incomprehensive | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Comprehensive |

| Experts | Exp 11 | Exp 12 | Exp 13 | Exp 17 | Exp 23 | Exp 24 | Exp 25 | Exp 28 | AVG. |
|---|---|---|---|---|---|---|---|---|---|
| **Scores** | 10 | - | - | 4 | 7 | 5 | 10 | 8 | 7.3 |

Expert 17 advises that different organisations have their own specific ways of assessing uncertainty. Therefore using the NUSAP pedigree criteria introduces rigidity into the uncertainty scoring process. However, he believes that this technique is more suitable to consultancies because it aids them in showing rigour in the justification of their uncertainty assessment. Expert 24 cautions that this area was the most complex for him in using the tool.

The responses to question (v) and the scale which was used to capture them in the questionnaire are illustrated in Table 9-16.

**Table 9-16:** Assess the Completeness/Suitability of the Framework for the Technique applied in deriving the Complexity Weight through Analytical Hierarchy Process - Ratings

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

| Experts | Exp 11 | Exp 12 | Exp 13 | Exp 17 | Exp 23 | Exp 24 | Exp 25 | Exp 28 | AVG. |
|---|---|---|---|---|---|---|---|---|---|
| Scores | 10 | - | - | 10 | 8 | 8 | 10 | 7 | 8.8 |

Expert 28 emphasises that the scoring process using the analytical hierarchy technique could be more intuitive.

The responses to question (vi) and the scale which was used to capture them in the questionnaire are illustrated in Table 9-17.

**Table 9-17:** Assess the Completeness/Suitability of the Framework for Deriving Complexity Levels using Pre-Defined Criteria - Ratings

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

| Experts | Exp 11 | Exp 12 | Exp 13 | Exp 17 | Exp 23 | Exp 24 | Exp 25 | Exp 28 | AVG. |
|---|---|---|---|---|---|---|---|---|---|
| Scores | 10 | 10 | 10 | 10 | 9 | 10 | 10 | 10 | 9.9 |

The responses to question (vii) and the scale which was used to capture them in the questionnaire are illustrated in Table 9-18.

**Table 9-18:** Assess the Completeness/Suitability of the Framework for Calculating the Complexity Score by Multiplying the Complexity Weight by the Complexity Level - Ratings

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

| **Experts** | **Exp 11** | **Exp 12** | **Exp 13** | **Exp 17** | **Exp 23** | **Exp 24** | **Exp 25** | **Exp 28** | **AVG.** |
|---|---|---|---|---|---|---|---|---|---|
| **Scores** | 10 | 7 | 7 | 8 | 6 | 7 | 9 | 6 | 7.5 |

## 9.6 Summary

In this chapter, the implementation and validation of the C-REACT framework was presented. A total of three case studies were used to validate the framework. Additionally, expert opinion was provided on the tool by eight experts from industry.

In Section 9.2, the research methodology which was adopted for the validation of C-REACT was presented. This section also provided the details of the experts involved in the validation.

Section 9.3 described the implementation of the C-REACT framework through development as a software tool in MS Excel, Visual Basic for Applications (VBA) and AnyLogic, detailing the architecture of the tool.

In section 9.4, each of the three case studies applied for the validation of C-REACT was presented. The results from each case study was illustrated and discussed. Additionally, the validation results obtained from the eight experts were discussed in Section 9.5, where an expert opinion analysis was provided.

The conclusion of this thesis is provided in the next chapter.

# 10 DISCUSSION AND CONCLUSIONS

## 10.1 Introduction

In Chapters 5 and 6, the development process of the proposed framework for assessing and estimating the cost of resource complexity was presented. The framework is embedded in a tool known as complexity for resource and assessment costing tool (C-REACT). The framework development was based on the observations which emerged from Chapter 2 (literature review) and Chapter 4 (current industrial practices). In Chapters 7 and 8, the framework consisting of two parts: (1) C-REACT for complexity identification and assessment, and (2) C-REACT for dynamic resource complexity costing was demonstrated. In Chapter 9, the implemented tool was validated by applying it to a total of 3 case studies and expert opinion provided by eight industry experts.

The purpose of this chapter is to provide a synopsis of the research findings and discuss their implications in the relevant field. Additionally, the conclusions inferred from this thesis are discussed in this chapter.

## 10.2 Discussion of Key Research Findings

This section discusses the key findings of this research. The discussion follows the sequence in which the thesis has been presented.

### 10.2.1 Literature Review

In order to obtain an indepth understanding of complexity and its relationship with ERP implementations and costing, the researcher conducted a comprehensive literature review in chapter 2. The focus of the study was on six key research fields which are enterprise resource planning (ERP), complexity, ERP project life cycle, ERP project costing, uncertainty, and dynamic modelling approaches. The focus for enterprise resource planning was in the ERP-specific complexities encountered in its implementations. Additionally, the impact of the complexities on implementation costs was studied. The effect of expensive ERP project resources on cost was also examined. In this study, ERP was highlighted as a very complex and costly undertaking in an organisation. ERP implementations often overrun on cost and schedule in an uncontrollable manner and this is often caused by its complexity. In an effort to address these complexities, organisations hire external resources to implement the ERP solution. These consultants are costly and as they encounter complexities, the implementation cost increases substantially. In relation to the complexity research field, the primary focus was on the meaning of complexity, complexity metrics and the classification of complexity. In the study, complexity theory is conveyed as seeking to understand how order and stability emerge from many interacting components. This is an indication that complexity is inherent in interrelationships. Furthermore, literature suggests that an increase in the number of relationships increases complexity. This relates to system behaviour. Therefore, complex systems present emerging, often chaotic behaviours which is known as emergence. Uncertainty also plays a key role in causing complexity as it constitutes a lack of awareness and understanding. Both emergence and uncertainty compose ambiguity. In this review, the researcher discovered that there is no standard definition for complexity. Instead, the causes of complexity are classified into ambiguity, system behaviour and human behaviour. It is further characterised as functional, structural and cognitive. There is very little literature on ERP complexity. Hence most of the studies on the complexity measure of its structure and function is dedicated to software development. As a result of this lack of complexity definition, this research defines complexity as the attribute of a system that makes that system difficult to use, understand, manage, implement, and/or has a potential to increase. It is inferred in literature review that the cost of software development is closely correlated with software complexity. Although, its measurement determines a system's failure or success, literature argues that there is no particular metric which measures software completely. Consequently, complexity is a combination of metrics of which the top four are the line of code (LOC), Halstead product metrics, McCabe's cyclomatic complexity metric and information flow. A fifth complexity metric which applies to ERP business process measure is control flow complexity metric. Complexity metrics are categorised as variety, variability, and integration. The lack of a complete metric for ERP implementation complexity drives the need for this research to propose one.

In order to measure complexity, the next research field which the literature review focused on, was ERP whole life cycle stages and implementation phases. This will enable the definition of ERP implementation activities within which complexities are inherent. Furthermore, the resources working on these activities, thereby experiencing the complexities will be allocated. There is a significant amount of study on the ERP project life cycle. To gain an understanding of the impact which complexity has on an ERP implementation cost, a technique is required for costing ERP implementation complexity. This was the next field of focus in Chapter 2. In this review, it emerged that several costing techniques exist for both software development and ERP implementation. However, most of the research on this topic concerns software development. Therefore, the estimation of ERP implementation projects has become a topic of growing importance, as there is not yet a widely accepted technique. Software growth increases software complexity, thereby causing a difficulty in estimation. This lack of a comprehensive costing technique for ERP implementation triggers a dire need for this research to develop and propose one. As the resource effort expended on ERP implementations results in a cost, and these resources experience the complexities which emerge in an activity, it is imperative to estimate the complexity cost for each resource. This calls for dynamic cost estimating, where the resources and their complexity costs are simulated for real-time visualisation. Therefore agent-based modelling was studied for this reason. Also, as uncertainty is a key part of complexity, this research field was a focus of the literature review. The entire literature review exposed the lack of a comprehensive complexity measure and costing technique for ERP implementation complexities. This drove the rationale for this research to focus on these areas for development.

### 10.2.2 Research Methodology

As discussed in Chapter 3, the research methodology adopted is predominantly qualitative. However, qualitative research is open to bias from the participants as well as the researcher. This is a weakness which may impede the validity and reliability of research findings. Therefore, the researcher employed a number of mitigation strategies to reduce bias in order to ensure trustworthy results. One of the strategies applied is triangulation by utilising various data collection methods. With this approach, data was collated from a number of sources. The researcher gathered data from face-to-face interviews, online surveys, telephone conferences, WebEx meetings, collection of documentation and reports from industry provided by collaborators, workshops, and a case study within industry using a semi-structured questionnaire. The questionnaire used in the online survey was slightly different from the one used in the interviews, but aimed to ask the same kind of questions. Several questionnaires were developed at different stages of the interviews and were piloted by an industrial expert for assurance of applicability. Minimising bias was also achieved by interviewing different experts from different organisations individually and collectively in workshops without disclosing their identities. Regular meetings were also conducted.

Both the researcher's and collaborators' bias was reduced by providing feedback from meetings to individual participants for the necessary amendments in the event of misinterpretation. Also refinement questionnaires were sent to all participants and discussed in workshops for collective feedback on the responses provided by individual participants. These questionnaires contained data produced by individual participants from previous meetings.

### 10.2.3 Current Industrial Practices

The researcher, after conducting face-to-face interviews which was based on a case study and recorded, managed to capture the current practice in relation to

ERP implementation challenges. These challenges were later linked to and described as complexities by the researcher. The case study demonstrated a lack of anticipation and preparation for these complexities. Consequently, they were difficult to control and resulted in twice the amount of the initial implementation cost estimate.

This case study presented the ideal scenario for problematic ERP implementations with numerous complexities. It was based on a large transport organisation with several legal entities, three of which participated in the case study. This automatically created a cross-case study for three case studies, as each legal entity implemented ERP separately and experienced different complexities to some extent. At the time of the implementation, the organisation was in the process of merging with another company, and this resulted in additional complexity. Additionally, as complexity increased, so did resources, thereby increasing the project cost. The implementation adopted a phased rollout by entity and module. A big bang approach was also employed by implementing a module across all the entities at the same time. The same modules were implemented in all three entities, and one programme sponsor was elected to manage the program across the relevant entities.

The rationale behind implementing ERP was driven by the organisation's need to replace their multiple legacy systems with one system. Their legacy systems were disparate. Another key driver was to integrate and streamline their business processes and policies due to their merge, in order to achieve standardisation and uniformity. Challenges manifested in the ERP project both during and after implementation. The problems experienced in the aftermath of the implementation were caused by the problems introduced during implementation. The researcher used five indicators to classify these challenges as complexities and to analyse the scale of each complexity. These indicators are complexities which make the system difficult to use, difficult to understand, difficult to manage, difficult to implement, and have a potential to increase.

The complexities in the case study highlighted the complexities which were studied in literature. It also emerged in this case study that complexity identification, assessment and costing had not been practiced. This is because a complexity measure does not exist for this purpose, and as a result, there is no means to calculate its cost. Additionally, the organisation did not have a structure for identifying and assessing ERP-specific complexities in order to gain an understanding of what they may face during implementation. This created a dire requirement in research for the development of an ERP complexity measure and associated costing technique to enable the identification, assessment and costing of ERP complexity.

### 10.2.4 Complexity Taxonomy and Work Breakdown Structure

Literature review highlights that the measurement of complexity is not new to software development environments. However, it is fairly new in ERP implementation scenarios. ERP projects do not really fail due to underestimation. They fail as a consequence of the complexities encountered. Without an assessment which will output a complexity measure, its cost will be difficult to measure, if not impossible. But in order to assess these complexities, they must be firstly identified and understood. In Chapter 5, a complexity taxonomy is proposed for this research. This taxonomy forms the platform for the identification and assessment of ERP implementation complexity. In addition to the taxonomy, a work breakdown structure (WBS) is defined in Chapter 6. This WBS is used to specify the activities where the complexities occur, and the resources who experience the complexities. This WBS will form the basis for costing the complexity.

The researcher defined an initial set of complexities obtained from literature review. In order to assess these complexities, ERP cost drivers were also studied. These cost drivers will be linked to the complexities for assessment. Literature review also provided a set of activities and resources for the WBS. Thereafter, the complexities, cost drivers and WBS elements were presented to industry through the case study undertaken in Chapter 4 and online surveys, for their feedback. The researcher classified the complexities into dimensions, and each dimension composes of a number of types. The next step was to invite industry collaborators to validate the concept of these items in order to incorporate them in a framework which will be defined in this research. The conceptual validation became an iterative refinement process. The results of the validation were a complexity taxonomy further broken down into a complexity dimension taxonomy and a complexity type taxonomy, a work breakdown structure and ERP cost drivers for this research. The complexity taxonomies formed a two-level complexity hierarchy known as the complexity breakdown structure (CBS).

As part of the complexity definition, the difficult to use, understand, manage, implement and potential to increase (UUMII) model was defined by the researcher. This model constitutes five indicators, each of which is used to determine the characteristic of a complexity from a 'difficulty' perspective. The characteristics enable an organisation to determine and understand the magnitude of each complexity as well as the reason for its difficulty. UUMII is also used to ascertain whether or not a challenge is a complexity. The indicators of this model drive the selection of resource types based on the kind of difficulty which a complexity will present.

The complexity dimensions were classified into six categories; variety, variability, integration, functional, structural and cognitive. These categories enable the definition of additional characteristics for each complexity. It enables an organisation to understand and identify where their efforts will lie in an implementation. Additionally, the researcher discussed the areas which are impacted by the proposed dimensions. These impact areas are based on the five indicators of the difficult to use, understand, manage, implement, and potential to increase (UUMII) model which is developed from the complexity definition of this research. Each complexity dimension was assigned to an impact area.

In Chapter 5, it was also highlighted that uncertainty, emergence and cost span the proposed complexity dimensions. Additionally, an increase in complexity increases cost. Complexity with variety, variability and cognitive properties are most likely to give rise to uncertainty and emergence. This causes a difficulty in the estimation and accurate planning of ERP implementations. Therefore, it is imperative to incorporate an uncertainty cost or justifiable contingency in the complexity cost. The current practice does not provide a framework for ERP uncertainty cost nor complexity identification and assessment. Hence this research proposes the relevant framework to address this issue.

### 10.2.5 Complexity Assessment Framework

In Chapter 7, the researcher highlighted the importance of complexity assessment for ERP implementations. This process is hardly addressed or discussed in research, and numerous implementations have failed and substantially exceeded their budget because of the lack of a complexity assessment. In the process of conducting a case study to ascertain current industrial practices, and validating the concepts of this research, industrial collaborators expressed the need for a comprehensive complexity assessment process in the ERP industry. It emerged that the traditional ERP project management treats complexity on an abstract level and it is based on analogy. A contingency is subsequently added to the overall project cost. However, due to the uncertainty of the data and its possible inaccuracy, the potential problems which may arise during implementation and the project cost are often underestimated.

C-REACT constitutes a framework that provides a standard procedure that elicits expert opinion which guides with complexity assessment and costing. C-REACT will be employed in the needs identification stage of an ERP whole life cycle project. It is composed of two parts. The first part which defines the process for complexity assessment is discussed in this section.

Due to the design of C-REACT, during the complexity assessment process, the user is provided with the opportunity to question the validity of the input data in a systematic manner. A key pre-requisite of the assessment process is the identification of complexities. This enables both the stakeholders and the expert to establish a thorough understanding of the complexities which would emerge during implementation. It is based on this identification that the assessment will be conducted. Additionally, the complexity assessment provides a platform upon which to consider factors which will affect the success of the potential implementation as well as its cost. This capability enables an early planning of the implementation, as well as the support to control and reduce the complexities.

A work breakdown structure is provided in the tool for the user to specify the activities which compose the project, and allocate resources to these activities. This allows the identified and assessed complexities to be classified according to the activity in which they appear. This classification forms the basis for costing the resource complexity as a consequence of the activity within which they function. The assessment process applies the analytical hierarchy process (AHP) in prioritising complexities by ranking their importance. The output of the AHP process is a weight of significance for each complexity. Furthermore, as C-REACT will be used in the needs identification stage, it is very likely that the user and expert will not be equipped with accurate and complete complexity data at that time. Hence the uncertainty of the estimates will be evaluated using a NUSAP pedigree matrix with an alternative manual uncertainty scoring function, which will be applied to the complexity dimensions. A further and final step is taken in the assessment process, which is the assignment of levels of complexity to each complexity type. This process is conducted by scoring cost drivers based on their complexity criteria. The complexity levels for the cost drivers are aggregated to form a complexity level for the complexity type to which they belong. The product of the complexity significance weight and the complexity level is used to generate a final complexity measure known as

Kessington's complexity number (KCN). This is used to classify the complexity within each activity.

The application of AHP, NUSAP and KCN for the assessment of ERP complexity does not exist in research or industry. The C-REACT complexity assessment process is comprehensive and this is lacked in research. The current complexity measures are more suited to software development and are not comprehensive. Therefore these measures proposed for complexity assessment are contribution to knowledge. The assessment process will support an organisation in its complexity control and reduction process which will ultimately reduce the implementation cost.

### 10.2.6 Cost Estimation of Resource Complexity Framework

In Chapter 8, the researcher presented the second part of the C-REACT framework which dynamically models the resource complexity cost estimate. The essence of this part of the framework is to enable the costing of complexities which have been identified and assessed for a potential ERP project. The cost of these complexities will be estimated according to the resources encountering the complexities. This allows an organisation contemplating an ERP solution to obtain an early view of the project cost estimates. In most ERP implementations reported in literature review, the current project estimates are often incorrect by substantial margins. This is because the projects overrun on cost as a result of complexities which emerge during implementation. These complexities are usually unanticipated, and consequently they are not incorporated in the project budget. The resource complexity cost estimate produced by C-REACT will be included in the project budget as part of the ERP system needs identification process. The estimate also enables an organisation to understand the areas of cost impact, thereby supporting them in controlling the costs by reducing the impacts.

The resource complexity cost modelling tool simulates the resource costs dynamically. It provides the user with a clear view of the points at which the complexity costs are incurred. It enables the user to visualise each resource as they work on an activity, and incur costs with and without complexity. This capability allows the stakeholders to run various scenarios based on different complexity types. This scenario analysis will provide real-time complexity cost estimates which will aid in informed decision making.

The tool is a composition of the following functionalities:

- Specification of a work breakdown structure which contains the project activities and resources for complexity costing. A three-point estimate is also used to define the effort required for the activity. This method is occasionally used in ERP project management in order to cater for uncertainty in the project. The resource rates for calculating the resource base cost is also specified through the WBS. The estimator is provided with the option to specify which activities are in a critical path. Additionally, direct cost estimates are provided through rate estimating for direct influence cost drivers. These estimates are used to update the relevant activities. A cost calculator is provided in the WBS for preliminary implementation costing.
- Cost drivers are mapped to complexity types in order to enable the scoring of complexities by complexity levels. This is also part of the complexity identification and assessment process.
- Access to the Kessington's complexity number which is already calculated as part of the complexity identification and assessment process. The KCN is applied to the base cost of each resource, as a percentage, and the result is the resource complexity cost.
- In the event that a complexity is in a critical path activity, and is assigned the highest complexity level, a contingency is calculated and added to the complexity cost. This caters for the uncertainty of what will happen as a consequence of a high complexity resource. The contingency amount is determined by using the uncertainty score. If the score falls

within an uncertainty range, the amount allocated to that range will be added to the complexity cost.

- A base, complexity and total cost is calculated for each resource. These amounts are run through Monte Carlo simulation for presentation of a cost distribution to apply in the resource cost estimate. The normal and log-normal distributions have proved to be a good fit.

### 10.2.7 Resource Complexity Cost Estimation with Agent-Based Modelling

Agent-based modelling (ABM) is a simulation technique which is adopted in this research for dynamic resource cost estimation. The purpose of employing this approach in this research is to perform cost estimation for each resource and visualise the costing process over time. The cost estimation emulates the resources as they work through their activities, experience complexities and incur complexity costs. Each resource is represented in ABM as an agent and they communicate with each other. Another reason for applying ABM is because it is known to address complex systems, and resource complexity costing falls into this category. The model is run for every resource which has its own set of activities and behaviours created as statecharts.

As the model runs through each resource, it enables them to perform their activities in parallel and sequentially according to the sequence number of the activity. It reads the activities and resource rates from the WBS through an interface. It also applies the three-point estimate for the effort required to complete each activity by each resource and produces a triangular distribution for each effort. The resource base cost is calculated for each resource. The model also reads the KCN through the interface file, converts it to a percentage and multiplies it by the resource base cost to obtain the resource complexity cost. Both the resource base cost and resource complexity cost are further added together to produce the resource total cost. This process is conducted through Monte Carlo which is run 1000 times to generate a normal and log-normal distribution.

The C-REACT framework validation participants indicated that the C-REACT is a comprehensive framework and will be extremely useful in industry for ERP project cost estimation.

### 10.2.8 Validation of the Developed System

C-REACT was validated through three industrial case studies. The key rationale behind the case study validation was to demonstrate the validity of the framework in different industrial sectors. All three case studies fulfilled this purpose. The case studies were validated through the banking, electronics manufacturing and aerospace manufacturing industries. Another purpose of the case studies was to prove the benefits accomplished by the relevant industries through the application of C-REACT. The participants from two of the case studies acknowledged that they had achieved the benefits offered by the framework. Both organisations are in the process of embarking on a new project, and have used this tool for their ERP implementation cost estimation. The results of the complexity assessment enabled them to focus on those areas in order to ensure that those complexities are minimised and avoided, where possible during implementation. They are confident that their project cost will reduce as a result of complexity control and reduction. Other benefits conveyed by the participants are improvement in the cost estimation process for ERP implementations, reduction in ERP failures, reduction in implementation time, improvements in decision making, and reduction in cost estimation time. This tool is also perceived by the case study participants as a platform for price negotiation between the potential ERP adopter and the ERP implementation consultancy.

In addition to the case study validation, C-REACT was also validated through eight experts from different industries and disciplines. These experts assessed the system by responding to the questionnaire with which they were provided. All the experts confirmed that the logic of the developed tool is valid, the system is generalizable, the system is flexible, it is easy to use, and it fits the purpose of complexity costing in the ERP discipline.

## 10.3 Main Contribution to Knowledge

This research offers an understanding of modelling complexity assessment and complexity cost estimating for potential ERP implementation resources at the needs identification stage by providing detailed frameworks which have been embedded in a software tool. It has produced a novel cost estimation system which enables potential ERP adopters to confidently make informed decisions about a potential ERP implementation and foreseeable complexities which might arise in the implementations. This research also enables organisations to understand the complexities which exist in an implementation from a resource perspective and supports complexity and cost reduction through resources. The focus of the research spans complexity identification, assessment, uncertainty evaluation, classification by complexity measure for activity, complexity correlation, the mapping of complexity types to cost drivers, parametric estimation of project activity duration, complexity contingency specification through uncertainty scoring, dynamic cost estimating through agent-based modelling, and Monte Carlo simulation of complexity cost estimation for ERP implementation resources.

The key contributions are summarised as follows:

- A new complexity identification method for ERP implementations. This research presents a complexity breakdown structure which is embedded in the tool. It develops a taxonomy of eleven complexity dimensions, and twenty-seven complexity types. The dimensions are business process complexity, customisation complexity, data cleansing and conversion complexity, external resource complexity, system configuration complexity, user complexity, organisational readiness complexity, project control complexity, internal resource participation complexity, module complexity and external factors complexity.

- The C-REACT framework enables a structured and formal decision making process by questioning assumptions and enabling an organisation to assess the significance and influence of complexities. The framework provides a novel approach to prioritise complexities in a systematic manner. The prioritisation approach transforms the traditional cost estimation process in the needs identification stage by introducing a formal complexity assessment process.
- The framework contributes to cost estimation in ERP implementations by producing a comprehensive taxonomy of eighty-one cost drivers, with each one mapped to the complexity type for which it is used as a measure. The determinant of the measure is one of a set of three criteria for each cost driver. Although the production of ERP cost drivers is not new in research, the cost drivers in this research are significantly more comprehensive than what literature currently offers. Additionally, these cost drivers are attached to complexity which makes this research novel as it introduces a complexity cost estimation method into research.
- The traditional process of adding contingency to ERP implementation estimates is transformed by this research. The contingency specification process in this research enables the uncertainty about the complexity estimates to determine the percentage which will be applied to the implementation cost. Furthermore, the contingency is performed at a line item level and for each resource, as opposed to what currently holds in industry which is applying contingency at a project level. Therefore, the source of contingency is justified and free of bias.
- This research enables the uncertainty associated with providing complexity assessment estimates to be evaluated and incorporated in the complexity cost. This uncertainty scoring allows a level of confidence to be attached to the complexity assessment, which is a new and distinctive method in research.
- The classification of complexity within the relevant project activity provides an organisation with an instant view of the areas in the project which will potentially manifest complexity based on its assessment.

Additionally, the classification indicates the amount of complexity within these activities, thereby allowing the organisation to understand which activities require the most and the least attention. This enables implementation resource planning and complexity reduction. The classification is presented with a new complexity measure, Kessington's complexity number (KCN) which is a novel metric in research because of its comprehensiveness and uniqueness to ERP implementations. KCN is applied to the cost estimates for each resource, as opposed to the activity and this provides another key area of contribution to knowledge.

- In addition to complexity assessment, this research provides a report to aid in the identification and understanding of complexity relationships by producing a complexity correlation matrix. This report informs an organisation of the emergent complexities which may be effected by other complexities. The emergent complexities result in hidden costs and will increase the complexity cost. These relationships have not been quantified for costing purposes. However, they raise awareness of emergent complexities. The correlation matrix is a new research area for ERP complexity management and control.
- A novel approach to demonstrate the influence of dynamic resource complexity costing is proposed in this research, using agent-based modelling. The focus is on the simulation of each resource working through its project activities and the visualisation of the cost accumulating during the process. The simulation presents the activities for each resource that has incurred a complexity cost. Simultaneously, it demonstrates the emergent costs of several resources working at the same time. It calculates the resource base cost, its complexity cost and the total resource cost dynamically. This capability enables an organisation to make well-informed decisions in real-time by conducting a scenario analysis.

## 10.4 Fulfilment of Research Aim and Objectives

This research has accomplished all seven objectives which have been outlined in Chapter 1. The first objective focused on investigating the complexity factors which are inherent in ERP implementations and defining a taxonomy for these complexities in order to aid complexity resource assessment and costing. To achieve this objective, the author fulfilled the following:

- Classified the complexities into eleven dimensions in a taxonomy; business process complexity, customisation complexity, data cleansing and conversion complexity, system configuration complexity, internal resource participation complexity, external resources complexity, user complexity, module complexity, project control complexity, organisational readiness complexity, and external factors complexity.
- Developed a taxonomy for twenty-seven complexity types
- Validated the proposed taxonomy of complexities where validation results indicate that the proposed taxonomy of complexities are comprehensive and provide a good foundation for complexity assessment

The second objective entailed designing a work breakdown structure which contains the implementation activities within which the identified complexities exist, and the resources for which the complexity cost is estimated. This process involved defining:

- fifty-three ERP implementation activities
- fourteen types of resource
- a default work breakdown structure
- three-point estimate efforts for each implementation activity
- a platform for specifying resource rates
- a cost calculator

The third objective concerned developing a technique for assessing ERP complexity. This composed of defining:

- a technique for prioritising and comparing complexity by importance using analytical hierarchy processing (AHP) through the guidance of applying importance ranks, which produce a weight as the result of the prioritisation.

- a technique to evaluate the uncertainty of the complexity assessment estimates by producing an uncertainty score
- five complexity levels using Likert scale to assess the scale of the relevant complexity
- Kessington's complexity number (KCN) which classifies each assessed complexity in its relevant project activity.
- a correlation matrix to inform the user of the complexities which will arise as a result of other complexities

The fourth objective involves analysing the cost drivers which enable the costing of complexity as follows:

- defining a taxonomy of eighty-one cost drivers for complexity cost estimation
- mapping each cost driver to its associated complexity
- defining three complexity levels; one of these will be used to score the relevant cost driver for which its complexity is being assessed
- defining a set of criteria for each cost driver

The fifth objective constitutes designing and developing a framework for assessing ERP implementation complexities. This activity involves:

- incorporating the WBS in the framework to enable three-point estimating of project activity effort, specification of project activity, allocation of project resource for base cost estimation of resources, and specification of critical path for the relevant project activities.
- incorporating the complexity taxonomy in the framework to allow for the identification of complexities
- incorporating the cost driver taxonomy in the framework to enable complexity assessment through complexity level scoring
- incorporating the complexity assessment method and process in the framework

- enabling the production of Kessington’s complexity number by multiplying the complexity weight with the complexity level, and classifying KCN in a project activity with the relevant complexity.
- enabling the variation of Kessington’s complexity number through the application of an uncertainty score
- producing a correlation matrix for all assessed complexities
- embedding the framework in microsoft excel

The sixth objective focused on designing and developing a framework for the dynamic cost estimation of resource complexity. This process caters for the following:

- building resources as agents through agent-based modelling
- developing statecharts for each agent to represent their relevant activities in the WBS
- calculating the base cost for each resource
- calculating the resource complexity cost by multiplying the base cost of each resource by KCN in the relevant activity
- calculating the total cost through 1000 runs in Monte Carlo simulation by adding the product of the base cost and KCN to the base cost
- embedding the framework in a simulation software package known as AnyLogic

The seventh objective entailed validation of the concepts of the frameworks by industrial collaborators, and validation of the tool through real life case studies and expert opinion.

## 10.5 Research Limitations

The focus of this research is on ERP implementations for large ERP organisations. The output of the research is a framework which will be used to assess and estimate the resource complexity cost of a potential ERP implementation. The developed framework known as complexity of resource and assessment costing tool (C-REACT) is used by ERP adopters in the Needs

Identification stage of an ERP project whole life cycle. This section presents the limitations of this research. These limitations concern the research methodology, the research tool implementation and the tool validation.

### 10.5.1 Research Methodology

The research was qualitative in nature and due to the human aspect of the research method, there was the possibility of bias in the interviews held with industry, the tool refinement and its validation. This would have affected the validity, reliability and replication of the results

In order to mitigate the bias and associated problems, the research data was collected through multiple resources. Interviews and a case study were conducted with industry. Online surveys were also performed in order to invite views from individual experts from different organisations and different roles. The interviews were recorded and well documented and analysed according to the research theme. In addition to questionnaires for obtaining information the first time around from industry, refinement questionnaires were also used to inform all participants of the decisions made by individual organisations, and to obtain their feedback about these decisions. Workshops were also run with participants from different collaborating organisation, whose identities were not disclosed. This provided the opportunity to eliminate bias by allowing experts to express their opinions without fear. Also, in the event that bias existed in any of the collective discussions, there were participants who opposed such discussions with different and more realistic views.

### 10.5.2 C-REACT Tool Implementation

At the initial stage of the interviews, sixty-three complexities were presented to industry for their feedback. At the end of the conceptual validation, eleven complexity dimensions were proposed with twenty-seven complexity types which are implemented in the tool. Although, more complexities can be accommodated in the tool in order to introduce a higher degree of comprehensiveness, this addition may reduce manageability and control of the complexity assessment.

The work breakdown structure has been tailored to ERP implementations and thoroughly validated prior to implementation. Therefore, the statecharts in the resource complexity costing part of the tool reflects the activities in the WBS through agent-based modelling. One of the limitations of ABM is that it does not provide the capability for additional states to be created dynamically. Consequently, additional activities cannot be dynamically created for resources in the event that a new activity is added to the WBS. Although this reflects rigidity in the costing model, it is essential that the model applies a pre-defined implementation methodology. Otherwise, if users are allowed to add and remove activities as and when they deem fit, this will reduce the quality of the tool which questions the accuracy of the results.

### 10.5.3 Validation of the Developed System

The tool was validated through three case studies. The organisations involved in the case study are from different sectors and were large organisations with previous experience of ERP implementations. Additionally, one of the participants represents both a consultancy and an ERP adopter, thereby bringing a wealth of experience to the case study. The other adopter also has indepth experience in ERP implementations and has been long-standing in this field. His case study represents a global organisation which had implemented ERP for most of its branches worldwide, and as a result experienced a myriad of complexities.

In addition to the three case studies, expert opinion of the tool was sought from eight experts from different industries and from different backgrounds. Their collaborative validation reduced any bias of both the researcher's and experts' opinions. Furthermore, although four of the experts participated in the conceptual validation and development of the framework, the other four did not which aids in counteracting any bias presented by the initially involved experts.

## 10.6 Conclusions

In conclusion, it may be asserted that this research study has achieved the main aim and objectives of developing a cost modelling framework to support resource complexity assessment and estimation of ERP implementations. This research has accomplished the following:

- The thesis has presented a review of techniques, metrics and methodologies for ERP complexity assessment and cost estimation to support the ERP needs identification process.
- The literature review identified a number of research gaps. The study generated a requirement for further work in ERP complexity identification, assessment and costing.
- The framework identifies and assesses potential ERP implementation complexities, and dynamically estimates the cost of these complexities by resource. In order to assess and cost the complexities, C-REACT utilises techniques like NUSAP pedigree matrix for uncertainty evaluation, analytical hierarchy processing (AHP) and a complexity criteria scoring mechanism for complexity assessment, and agent-based modelling with Monte Carlo simulation for resource complexity cost estimation.
- The developed cost modelling framework produced a taxonomy of eleven complexity dimensions, a second taxonomy of twenty-seven complexity types, eighty-one cost drivers, three alternative complexity scoring criteria for each cost driver, a complexity measure known as Kessington's complexity number (KCN) for classification of complexities, a complexity matrix, a generic ERP work breakdown structure, and a three-point duration estimation technique. This system has been developed in Microsoft excel using visual basic for applications (VBA) and Anylogic.
- C-REACT was validated through three case studies within the banking, aerospace and electronics industries. The validation demonstrated that the tool is applicable for use in diverse disciplines. The developed tool

can be used to identify, assess and cost resource complexities in real ERP implementations.

## 10.7 Recommendations for Future Research

Literature review revealed a number of areas which are currently lacking in research. One of the areas is that research has not yet developed a comprehensive metric for measuring ERP complexity. This causes a difficulty in both the measurement and cost estimation of ERP resource complexity. Secondly, a comprehensive costing technique for ERP implementation complexity does not exist. It is for these reasons that this research has developed a framework to measure and cost complexity through its identification and assessment processes. In the process of developing the framework for complexity of resource and assessment costing, a number of techniques have been defined to support the tool.

### 10.7.1 Work Breakdown Structure

The WBS provided by C-REACT focuses on offshore resources from a complexity perspective. This type of resource is normally used on ERP projects in order to reduce the resource cost. Therefore, whilst the tool produced by this research enables the complexity on this resource type to be assessed, it does not cater for its direct cost. It was discovered by the researcher and a participant of one of the case studies that the resources who contribute the most to complexity cost are the functional and technical consultants. However, in the case studies, these resources are senior consultants and their rates are in sterling. In the event that their tasks are shared with offshore resources, although the complexity assessment may increase, the cost might reduce. Therefore it is recommended that a type of resource to represent offshore consultants, are defined in research, in order to advance the tool and enable a variation in complexity cost.

### 10.7.2 Complexity Identification

The current taxonomy embedded in C-REACT which is used in identifying complexities consists of eleven dimensions. Although all the participants of the framework validation are satisfied with this quantity, it would be useful in future to investigate and incorporate additional complexities which may arise in future ERP implementations. This will extend the taxonomy and enable additional scenario analysis.

Future research should be dedicated to identifying country-specific ERP complexities in order to enable different countries to perform a complexity assessment and costing which applies to their peculiar circumstances and scenarios based on their legislation. This will enable their cost estimates to accommodate additional scenarios. This investigation should also be extended to identifying company-specific scenarios for incorporation in the framework.

This research addresses complexity without a distinction of its goodness. Some complexities are good because they provide benefits to an organisation and this makes them compulsory in certain circumstances. Hence it is recommended that in future research, complexities are identified and assessed according to their goodness in order to allow a company to understand why they must retain certain complexities despite their high cost.

### 10.7.3 Complexity Assessment

Analytical hierarchy processing (AHP) was applied in this research for prioritising complexities based on their importance. Whilst all participants of the tool validation are satisfied with this technique, in future, it would benefit organisations to understand the difference between AHP and other techniques in relation to C-REACT. Additional MCDM techniques for consideration are fuzzy set theory, case-based reasoning (CBR), simple multi-attribute rating technique (SMART) amongst others.

C-REACT addresses ERP complexity assessment and costing for implementation resources. However, in the event that the assessment scores are presented to the user, they are expected to manage the control of the potential complexities by themselves. Future research should develop mitigation strategies for the complexities to guide the organisation in reducing, possibly eliminating, controlling and managing the complexities. This will save the organisation the time in discussing complexity control and management strategies.

The cost drivers presented in this research are not assessed using AHP. Future research should develop a framework which caters for the prioritisation of cost drivers according to their significance, in relation to their complexity types. This would introduce an additional capability for extended scenario analysis and variation of KCN.

### 10.7.4 Complexity Classification

The classification of complexities in activities is presented as a Kesington's complexity number (KCN) in C-REACT. This number is applied to each resource in the relevant project activity to which KCN is assigned. In future research, the possibility to vary complexity costing by dividing KCN by the number of resources, should be developed. The results should be compared with the estimates produced in C-REACT without the division factor for KCN, and further compared with actual cost estimates in order to establish the more suitable complexity number for cost estimating.

### 10.7.5 Complexity Correlation

The correlation complexity matrix defined in this research raises awareness of the effects which each complexity has on other complexities. This correlation was thoroughly validated by industrial collaborators. However, the financial impact of the correlation is not considered in C-REACT. Therefore it is recommended that the cost of complexity correlation be developed in future research. This will enable a potential ERP adopter to understand, assess and estimate the cost of the relationships amongst complexities as these are hidden costs which will most likely manifest in implementations.

### 10.7.6 Dynamic Resource Complexity Cost Estimation

The current tool of this research is applied to the direct costing of ERP complexities. In future research, the schedule of the activities should be the basis of the complexity costing. Each project should be compared to similar projects and the difference in effort calculated. The result should be defined as the complexity time which is used to calculate the complexity cost through parametric estimating.

Secondly, the effect of the complexities on time should be defined in future research. This will enable an organisation to assess a potential ERP implementation schedule in addition to cost. This information will allow them to decide whether or not they can afford the estimated schedule and whether they have the respective resources in the organisation to deploy to the ERP implementation.

In the event that a new activity or new resource type is added to the work breakdown structure, this research does not provide a dynamic addition to the statecharts in the agent-based model. Future research should advance this dynamic complexity cost estimation model to accommodate new activities and resources in the WBS. This will provide flexibility in incorporating activities into the tool which are not currently considered. This will also encourage organisation with unique activities and resource types to use the model.

Although agent-based modelling was applied to the dynamic complexity cost estimating process in this research, it is recommended that other modelling techniques be applied in future research. This would enable a comparison amongst different modelling techniques in order to determine the most suitable one for complexity costing. Even though ABM is suitable for this research because it addresses the resources of ERP implementation projects, other techniques might treat resource complexity costing from different perspectives. Furthermore, all the techniques could be combined in future research for resource complexity cost estimation to allow a comparison with the current tool of this research and the individual techniques presented by future research.

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# Appendix A Questionnaires

## A.1 Questionnaire for Identifying Complexity Factors for ERP Whole Life Cycle

| Purpose |
| --- |
| This questionnaire is targeted at establishing the factors that contribute to the costing and complexity of an ERP (Enterprise Resource Planning) whole life cycle (WLC). In today's world, estimating the cost of an ERP implementation project is more widely practiced than costing the whole life cycle of an ERP solution. WLC alludes to the life span of any asset/service from pre-acquisition to disposal. Therefore, WLC costing (WLCC) entails costing the whole life of a asset/service (ERP solution in this case) from the activities conducted before its acquisition, through its design and implementation, to activities conducted during its disposal.<br><br>The primary purpose of WLCC is to aid capital investment decision making by providing forecasts of the long-term costs of implementation and ownership of an asset. This enables the sponsor of the asset to determine whether or not, the asset is affordable and worthy of the expenditure.<br><br>WLCC also has its challenges in the sense that it is not commonly practiced. Hence, there is a dire need to bring its importance to the fore. Exercising whole life cycle costing will make ERP acquisition decisions easier and better informed.<br><br>This questionnaire collates answers from various companies and individuals that have been involved in an ERP implementation at one time or other. The questions centre on the cost drivers used (if at all) during the estimation of the project budget, as well as the factors that contributed to the complexity of the project. This will enable the author to ascertain whether or not, a cost model was used in costing the project. The answers from the questionnaire will also identify the complexity factors that affect the costing of the ERP solution whole life cycle.<br><br>The long-term objective of this exercise is to develop a model which will be used to cost the whole life cycle of an ERP solution. The model will also enable the costing to be performed by reducing complexity throughout the ERP life cycle.<br>The answers collated in this questionnaire are compared to answers provided by other participating organizations, and a joint report is produced at the end of all the interviews.<br><br>The participating organizations are referred to in the report, with their consent. **BUT THE CHALLENGES DETAILED IN THE REPORT DO NOT REFER TO ANY COMPANY, IN PARTICULAR.** The challenges are jointly published in the report, across the board. |

| | | | |
|---|---|---|---|
| **Research Title:** | **Identifying Costing and Complexity Factors for ERP Whole Life Cycle** | **Date of Interview:** | **07/04/2010** |
| **Company/Location:** | **XXX** | **ERP Product:** | **XXX** |
| **Interviewee(s):** | **XXX** | **Function/Department:** | **XXX** |
| **Job Title:** | **XXX** | **Author:** | **Aisha Momoh** |
| **FOR ANSWERS THAT YOU WISH TO ELABORATE UPON, PLEASE USE THE SPACE PROVIDED BELOW EACH ITEM TO TYPE (OR PRINT) YOUR ANSWERS IN ITALICS** | | | |
| **PART A – COMPLEXITY AND COSTING** | | | |
| (1) Which industry is your organization in? | | | |
| (2) What is the nature of the business operated by your organization? | | | |
| (3) Please select which option below applies to your company<br>☐ Group | | | |

☐ Single Entity

☐ Other

(4) What is the size of your company in terms of staff strength?

☐ 1 - 50

☐ 50 - 100

☐ 100 - 250

☐ 250 - 500

☐ > 1000

☐ Other

(5) What is your annual turnover in dollars?

☐ Less than 10,000

☐ Between 10,000 and 50,000

☐ Between 50,000 and 250,000

☐ Between 250,000 and 1,000,000

☐ Other

(6) Which of the following levels does your position fall into?

☐ Executive Management

☐ Senior Business Management

☐ Junior Management

☐ Non-Management

☐ Other

(7) Has ERP been implemented in your company?

☐ Yes

☐ No

☐ Other

(8) Were you involved in the ERP solution whole life cycle of (7) above or any other?

☐ Yes

☐ No

(9) What was your role in the whole life cycle?

☐ Project Champion ☐ Project Sponsor ☐ Project Manager

☐ Change Manager ☐ Subject Matter Expert ☐ Infrastructure Specialist

☐ Programmer ☐ Business Process Analyst ☐ Integration Specialist

☐ Configurer ☐ Tester ☐ Trainer

☐ Other ☐ Support Specialist

(10) What drove the need for an ERP solution?

(11) Was there a formal business case for the ERP solution?

☐ Yes

☐ No

(12) Did the business undergo a formal ERP application selection process?

☐ Yes

☐ No

(13) Was an implementation methodology used?

☐ Yes

☐ No

(*If you have ticked 'Yes' above, please go to question 14*.)

(14) Which methodology was employed?

☐ AIM

☐ ASAP

☐ Other

(15) Was the project completed according to time and budget?

☐ Yes

☐ No

(16) Did the delivered solution produce the expected results?

☐ Yes

☐ No

☐ Other

(17) Which of the following factors were considered during selection?

☐ Cost ☐ Time ☐ Resourse

☐ Business Requirements ☐ Best Practice Processes ☐ Geographical Location

☐ Nature of Business ☐ Other

*(If you have ticked "Other" above, please elaborate in space below)*

(18) Are there other factors that could have been considered during the selection process?

☐ Yes

☐ No

*(If you have ticked "Yes" above, please elaborate in space below)*

(19) Did the ERP project budget cover costs from pre-acquisition to disposal?

☐ Yes

☐ No

*(If you have ticked "Yes" above, please go to question 20.)*

(20) At what stage was the whole life cycle considered for the ERP project?

☐ Pre-Selection

☐ During Selection

☐ Post-Selection

(21) Was the support stage considered during your ERP implementation?

☐ Yes

☐ No

(22) What are the stages in the ERP whole life cycle?

☐ Needs Identification

☐ Package Evaluation & Selection

☐ Implementation

☐ Post-Go-Live Support

☐ Maintenance

☐ Decommission

☐ Other

(23) Do you consider ERP projects complex?

☐ Yes

☐ No

*(If you have ticked "Yes" above, please elaborate in space below)*

(24) What are the factors that makes ERP whole life cycle complex?

***(Please select the top 20)***

| | | | |
|---|---|---|---|
| ☐ System Configuration | ☐ Reliance on Third Party Labour | ☐ Nature of Contract | ☐ Level of Internal Resource Participation |
| ☐ Number of Users | ☐ Level of Negative Predisposition | ☐ Countries | ☐ Experience with Technology |

☐ Languages ☐ Readiness ☐ Security Status

☐ Departments ☐ Level of Availability of Experienced Resource ☐ Conversion Effort of Level of Data Misfit ☐ Extent of System Redesign after Pilot

☐ Team Members Overall Acumen ☐ Process Relationships ☐ Extent of Goal and Scope Change ☐ Number of Affected Locations

☐ Business Processes ☐ Structural Integration ☐ Activity ☐ Data / Information

☐ Functions ☐ Modules ☐ Difference in Business Units ☐ Level of Customization

☐ Number of Systems to be Replaced ☐ Application Size ☐ Social Integration

☐ Schedule

☐ Difference in Terminology ☐ Connectivity ☐ Power Failure

☐ Other

*(If you have ticked "Other" above, please elaborate in space below.)*

(25) Is there a correlation between any of the complexity factors in question (24) above?

☐ Yes

☐ No

*(If you have ticked "Yes" above, please go to question 26)*

(26) For each selected complexity factor in question (24) above, specify its correlated complexity factor in the given space next to it below:

☐ System Configuration ☐ Reliance on Third Party Labour

| | | | |
|---|---|---|---|
| ☐ Nature of Contract | | ☐ Level of Internal Resource Participation | |
| ☐ Number of Users | | ☐ Level of Negative Predisposition | |
| ☐ Countries | | ☐ Experience with Technology | |
| ☐ Languages | | ☐ Readiness | |
| ☐ Security Status | | | |
| ☐ Departments | | ☐ Level of Availability of Experienced Resource | |
| ☐ Conversion Effort of Level of Data Misfit | | ☐ Extent of System Redesign after Pilot | |
| ☐ Team Members overall acumen | | ☐ Process Relationships | |
| ☐ Extent of goal and Scope Change | | ☐ Number of affected Locations | |
| ☐ Business Processes | | ☐ Structural Integration | |
| ☐ Activity | | ☐ Data / Information | |
| ☐ Functions | | ☐ Modules | |
| ☐ Difference in Business Units | | ☐ Level of Customization | |
| ☐ Number of systems to be replaced | | ☐ Application Size | |
| ☐ Social Integration | | ☐ Schedule | |
| ☐ Difference in Terminology | | ☐ Connectivity | |

☐ Power Failure

*(If you have ticked "Other" in question 24, please cater for the complexity factors you specified in the space below.)*

(27) Are all the complexity factors measurable?

☐ Yes

☐ No

(28) List the complexity factors that apply to each stage of the ERP whole life cycle?

☐ Needs Identification

☐ Package Evaluation & Selection

☐ Implementation

☐ Post-Go-Live Support

☐ Maintenance

☐ Decommission

☐ Other

(29) Would you consider an ERP whole life cycle costly?

☐ Yes

☐ No

(30) What are the cost drivers that contribute to an ERP whole life cycle?

***(Please select the top 20)***

| | | |
|---|---|---|
| ☐ Cost of Database | ☐ Software License | ☐ Number of Employees |
| ☐ Number of Sites | ☐ Hardware | ☐ Number of Business Processes |
| ☐ Network Infrastructure | ☐ Internal Issues | ☐ Level of Project Team Experience |
| ☐ Type of Company | ☐ Labour Cost | ☐ Country |
| ☐ Backfilling | ☐ Security Status | ☐ Accommodation |
| ☐ Office Space | ☐ Interfaces | ☐ Vehicle for Logistics |
| ☐ Third Party Product | ☐ Hardware Upgrade | ☐ Business Process Re-engineering |
| ☐ Communication | ☐ Modules | ☐ Contingency |
| ☐ Configuration | ☐ Level of Integration | ☐ Number of Legacy Applications |
| ☐ Data Cleansing | ☐ Data Conversion | ☐ Cost of Upgrading ERP software |
| ☐ Software Maintenance | ☐ Change in Scope | ☐ Changes Made on ERP Application |
| ☐ Training | ☐ Change Management | ☐ Evaluation of New software |
| ☐ Procurement Process | ☐ Testing | ☐ Slow Decision Making |
| ☐ Documentation | ☐ Report Generation | ☐ Cost of Workforce Unavailability |
| ☐ Schedule Overrun | ☐ Terms of contract | ☐ Travel Cost |
| ☐ Size of company | ☐ Disruption of business | ☐ Cost of Assessing End of life Span |
| ☐ Generator for Electricity | ☐ Availability of Database | ☐ Connectivity |
| ☐ Other | | |

*(If you have ticked "Other" above, please elaborate in space below.)*

(31) Are all cost drivers measurable?

☐ Yes

☐ No

(32) Is there a correlation between the complexity and costing of an ERP whole life cycle project?

☐ Yes

☐ No

(33) For each selected cost driver in question (30) above, specify its correlated complexity factor(s) in the given space next to it below

| | | | |
|---|---|---|---|
| ☐ Cost of Database | | ☐ Software License | |
| ☐ Number of Sites | | ☐ Hardware | |
| ☐ Network Infrastructure | | ☐ Internal Issues | |
| ☐ Type of Company | | ☐ Labour Cost | |
| ☐ Backfilling | | ☐ Security Status | |
| ☐ Office Space | | ☐ Interfaces | |
| ☐ Third Party Product | | ☐ Hardware Upgrade | |
| ☐ Communication | | ☐ Modules | |
| ☐ Configuration | | ☐ Level of Integration | |
| ☐ Data Cleansing | | ☐ Data Conversion | |

| | | | |
|---|---|---|---|
| ☐ Software Maintenance | | ☐ Change in Scope | |
| ☐ Training | | ☐ Change Management | |
| ☐ Procurement Process | | ☐ Testing | |
| ☐ Documentation | | ☐ Report Generation | |
| ☐ Schedule Overrun | | ☐ Terms of contract | |
| ☐ Size of company | | ☐ Disruption of business | |
| ☐ Generator for Electricity | | ☐ Availability of Database | |
| ☐ Number of Employees | | ☐ Number of Business Processes | |
| ☐ Level of Project Team Experience | | ☐ Country | |
| ☐ Accommodation | | ☐ Vehicle for Logistics | |
| ☐ Business Process Re-engineering | | ☐ Contingency | |
| ☐ Number of Legacy Applications | | ☐ Cost of Upgrading ERP software | |

☐ Changes Made on ERP Application

☐ Evaluation of N... f...

☐ Slow Decision Making

☐ Cost of Workforce Unavailability

☐ Travel Cost

☐ Cost of Assessing End of life Span

☐ Connectivity

☐ Other

*(If you have ticked "Other" above, please elaborate in space below.)*

(34) Did you assess the ROI (Return on Investment) of the ERP product?

☐ Yes

☐ No

(35) How many years do you estimate your ERP solution to last for?

☐ 1 - 3 years

☐ 3 - 9 years

☐ 9 - 15 years

☐ 16 - 20 years

☐ Other (please specify) As long as you want to u

(36) How would you determine when to dispose of your ERP solution?

(37) What was the budget (in dollars) for the ERP project?

(38) Which of the following stages did the budget cover?

- ☐ Needs Identification
- ☐ Package Evaluation & Selection
- ☐ Implementation
- ☐ Post-Go-Live Support
- ☐ Maintenance
- ☐ Decommission
- ☐ Other (please specify)

(39) Was there any contingency?

- ☐ Yes
- ☐ No

(40) Was the project budget exceeded?

- ☐ Yes
- ☐ No

*(If you have ticked "No" above, please explain what the excess, if any, was used for in space below.)*

(41) Have you realized your ROI (Return of Investment)?

☐ Yes

☐ No

(42) What benefits were you expecting to reap from the ERP solution?

(43) Have changes been made to the system since it entered its operational stage?

☐ Yes

☐ No

*(If you ticked "Yes" above, please go to question 44.)*

(44) What kind of changes were made to the system?

Processes and complimentary routines.

(45) Were these changes anticipated in the previous project stages?

☐ Yes

☐ No

(46) Do you monitor the performance of the system?

☐ Yes

☐ No

(47) When the system has reached its end of life, would you dispose of it?

☐ Yes

☐ No

(48) Prior to selecting the ERP system, did you have a costing tool that allowed you to cost the entire life of the system, from pre-acquisition to disposal?

☐ Yes

☐ No

*(If you ticked "No" above, please go to question 49.)*

(49) Would you have preferred to have a costing tool?

☐ Yes

☐ No

*(If you ticked "Yes" above, please go to question 50.)*

(50) What would you have expected from the costing tool?

(51) Would you consider the ERP implementation successful?

☐ Yes

☐ No

(52) How would you define ERP whole life cycle success for your organisation?

Additional Comments

INTERVIEWEE'S SIGNATURE______________________________________________

DATE *(dd-mm-yyyy)* ____________________________

## A.2 Questionnaire to Validate Concept of ERP Complexity Costing Model – Part A: ERP Project Activities and Resourcing

| Aim |
|---|
| This questionnaire aims to enable an ERP (Enterprise Resource Planning) expert to validate the project activities and resources which will be simulated to cost the resource complexities in an ERP project.<br><br>The ERP (Enterprise Resource Planning) costing project aims to develop a model that will predict the cost of complexity for each key stakeholder, in an ERP implementation project over time. This model will enable a more controlled and efficient project costing from the start of implementation to its end. It presents organisations with an early view of the potential cost and associated complexities which they could be faced with, from a stakehoder perspective. The model simulates the impact of stakeholder complexities on cost and time. The stakeholders are the project resources and they are presented in the model as agents with Agent-Based Modelling (ABM) techniques.<br><br>The opinions captured in this questionnaire are compared to those provided by other participating organisations, and the model is adjusted according to suggestions made, where necessary. A report of the validation is produced at the end of the validation exercise. |

**Researcher:** Aisha Momoh

**Supervisors:** Dr. Essam Shehab, Professor Rajkumar Roy

**Date:**

Name of Participant:……………………………………………………….

Organisation:………………………………………………………………….

Role:……………………………………………………………………..

Industry:……………………………………………………………………….

Years of Experience in Project Management:………………………………..

Project Management Experience in the following areas:

(*Please tick the relevant boxes*)

ERP Project Management ☐

IT/IS Project Management ☐

ERP Implementation Experience in the Following Solutions:

(*Please tick the relevant boxes*)

SAP ☐ Other ☐ *if other, please specify:*…………………..

ORACLE ☐

**Task 1: Provide your perspective of an ERP project methodology**

………………………………………………………………………………………

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**Task 2: Evaluate the ERP project activities**

(*Please apply the scores below to each ERP project activity below in the third column)*

| Strongly Incorrect | Incorrect | Neither Correct nor Incorrect | Correct | Strongly Correct |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

| **Stage** | **Activity** | **Correctness Score of Activity** | **Comments** |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Implementation | Project Preparation | | |
| Implementation | Business Blueprint | | |
| Implementation | Realisation | | |
| Implementation | Final Preparation | | |
| Implementation | Go-Live | | |

If there are any deficiencies, please describe them:

……………………………………………………………………………………………

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Do you have any suggestions for improvement?

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**Task 3: Evaluate the ERP project sub-activities**

(*Please apply the scores below to each ERP project sub-activity below in the third column)*

| Strongly Incorrect | Incorrect | Neither Correct nor Incorrect | Correct | Strongly Correct |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

| **Activity** | **Sub-Activity** | **Correctness** | **Comments** |
|---|---|---|---|

| | | Score of Sub-Activity | |
|---|---|---|---|
| Project Preparation | Develop Work Plan | | |
| Project Preparation | Assemble Steering Committee and Project Manager | | |
| Project Preparation | Define Project Goals, Scope and Implementation Approach | | |
| Project Preparation | Allocate Resources | | |
| Project Preparation | Clarify Implementation Scope | | |
| Project Preparation | Define Implementation Strategy | | |
| Business Blueprint | Build AS-IS model | | |
| Business Blueprint | Analyse Current Business Processes | | |
| Business Blueprint | Identify Existing Gaps | | |
| Business Blueprint | Investigate ERP Functionalities | | |
| Business Blueprint | Identify Need for Business Process Re-Engineering/Customization | | |
| Business Blueprint | New Process Design Mapping | | |
| Business | ERP Acquisition | | |

| | | | |
|---|---|---|---|
| Blueprint | | | |
| Business Blueprint | Hardware Acquisition/Upgrade | | |
| Realisation | Build System Prototype | | |
| Realisation | Pilot Each Process Design | | |
| Realisation | Create Forms and Reports | | |
| Realisation | Configure System | | |
| Realisation | Perform Data Cleansing | | |
| Realisation | Develop Conversion Programs | | |
| Realisation | Develop Interface Prpgrams | | |
| Realisation | Establish User Access Rights | | |
| Realisation | Create Training Manual | | |
| Realisation | Develop Test Plans | | |
| Realisation | Conduct Unit Testing | | |
| Final Preparation | Conduct Integration Testing | | |
| Final Preparation | Installation | | |
| Final Preparation | Train Users | | |
| Final Preparation | User Acceptance Testing | | |
| Final Preparation | Modify and Fine-Tune System | | |

| | | | |
|---|---|---|---|
| Final Preparation | Data Migration | | |
| Go-Live | Launch ERP System | | |
| Go-Live | Plan Resources to Provide Support | | |
| Go-Live | Parallel Runs Test | | |
| Go-Live | Detect and Record Anomalies | | |

If there are any deficiencies, please describe them:

…………………………………………………………………………………………

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Do you have any suggestions for improvement?

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**Task 4: Evaluate the ERP sequence of each project sub-activity**

(*Please apply the scores below to each ERP project sub-activity sequence below in the fourth column)*

| Strongly Incorrect | Incorrect | Neither Correct nor Incorrect | Correct | Strongly Correct |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

| Activity | Sub-Activity | Sequence | Correctness Score of Sequence | Proposed Sequence | Comments |
|---|---|---|---|---|---|
| Project Preparation | Develop Work Plan | 1 | | | |
| Project Preparation | Assemble Steering Committee and Project Manager | 2 | | | |
| Project Preparation | Define Project Goals, Scope and Implementation Approach | 3 | | | |
| Project Preparation | Allocate Resources | 4 | | | |
| Project Preparation | Clarify Implementation Scope | 5 | | | |
| Project Preparation | Define Implementation Strategy | 6 | | | |
| Business Blueprint | Build AS-IS model | 7 | | | |
| Business Blueprint | Analyse Current Business Processes | 8 | | | |
| Business Blueprint | Identify Existing Gaps | 9 | | | |
| Business Blueprint | Investigate ERP Functionalities | 10 | | | |
| Business Blueprint | Identify Need for Business Process Re-Engineering/Customization | 11 | | | |
| Business | New Process Design | 12 | | | |

| | | | | | |
|---|---|---|---|---|---|
| Blueprint | Mapping | | | | |
| Business Blueprint | ERP Acquisition | 4 | | | |
| Business Blueprint | Hardware Acquisition/Upgrade | 4 | | | |
| Realisation | Build System Prototype | 13 | | | |
| Realisation | Pilot Each Process Design | 14 | | | |
| Realisation | Create Forms and Reports | 13 | | | |
| Realisation | Configure System | 13 | | | |
| Realisation | Perform Data Cleansing | 13 | | | |
| Realisation | Develop Conversion Programs | 14 | | | |
| Realisation | Develop Interface Programs | 15 | | | |
| Realisation | Establish User Access Rights | 10 | | | |
| Realisation | Create Training Manual | 15 | | | |
| Realisation | Develop Test Plans | 16 | | | |
| Realisation | Conduct Unit Testing | 17 | | | |
| Final Preparation | Conduct Integration Testing | 18 | | | |
| Final Preparation | Installation | 19 | | | |
| Final Preparation | Train Users | 20 | | | |
| Final Preparation | User Acceptance Testing | 21 | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Final Preparation | Modify and Fine-Tune System | 21 | | | | |
| Final Preparation | Data Migration | 22 | | | | |
| Go-Live | Launch ERP System | 23 | | | | |
| Go-Live | Plan Resources to Provide Support | 24 | | | | |
| Go-Live | Parallel Runs Test | 25 | | | | |
| Go-Live | Detect and Record Anomalies | 25 | | | | |

If there are any deficiencies, please describe them:

…………………………………………………………………………………………

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Do you have any suggestions for improvement?

…………………………………………………………………………………………

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**Task 5: Evaluate the ERP Resource Types**

(*Please apply the scores below to each ERP project resource type below in the third column)*

| Strongly Irrelevant | Irrelevant | Neither Relevant nor Irrelevant | Relevant | Strongly Relevant |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

| **Resource Type** | **Resource Type Description** | **Relevance of Resource** | **Remove Resource (mark cell with 'X')** | **Newly Proposed Resource** | **Comments** |
|---|---|---|---|---|---|
| FCON | Functional Consultant | | | | |
| TCON | Technical Consultant | | | | |
| FSME | Functional Subject Matter Expert | | | | |
| TSME | Technical Subject Matter Expert | | | | |
| PO | Process Owner | | | | |
| KU | Key User | | | | |
| AM | Account Manager | | | | |
| EPM | External Project Manager | | | | |
| IPM | Internal Project Manager | | | | |
| SADM | Systems Administrator | | | | |
| PA | Project Auditor | | | | |
| TR | Trainer | | | | |

If there are any deficiencies, please describe them:

…………………………………………………………………………………………

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Do you have any suggestions for improvement?

…………………………………………………………………………………………

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**Task 6: Assess the relevance of each type of resource for each ERP project sub-activity**

(*Please apply the scores below in brackets next to each resource type specified with 'X' for each sub-activity)*

| Strongly Irrelevant | Irrelevant | Neither Relevant nor Irrelevant | Relevant | Strongly Relevant |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

| | **Relevance** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sub-Activity** | **Functional Consultant** | **Technical Consultant** | **Functional Subject Matter Expert** | **Technical Subject Matter Expert** | **Process Owner** | **Key User** | **Account Manager** | **External Project Manager** | **Internal Project Manager** | **Systems Administrator** | **Trainer** | **Project Auditor** |
| Develop Work | | | | | | | | X | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plan | | | | | | | | | | | | |
| Assemble Steering Committee and Project Manager | | | | | | | | X | | | | |
| Define Project Goals, Scope and Implementation Approach | | | | | | | | X | | | | |
| Allocate Resources | | | | | | | | X | | | | |
| Clarify Implementation Scope | | | | | | | | X | | | | |
| Define Implementation Strategy | | | | | | | | X | | | | |
| Build AS-IS model | X | | X | | | | | | | | | |
| Analyse Current Business Processes | X | | X | | | | | | | | | |
| Identify Existing Gaps | X | | X | | | | | | | | | |
| Investigate ERP Functionalities | X | | X | | | | | | | | | |
| Identify Need for Business Process Re-Engineering/Customization | X | | X | | | | | | | | | |
| New Process | X | | X | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Design Mapping | | | | | | | | | | | | |
| ERP Acquisition | | | | | | | | X | X | X | | |
| Hardware Acquisition/Upgrade | | | | | | | | X | X | | | |
| Build System Prototype | X | | X | | | | | | | | | |
| Pilot Each Process Design | X | | X | | | | | | | | | |
| Create Forms and Reports | | X | | X | | | | | | | | |
| Configure System | X | | X | | | | | | | | | |
| Perform Data Cleansing | | X | | X | | | | | | | | |
| Develop Conversion Programs | | X | | X | | | | | | | | |
| Develop Interface Prpgrams | | X | | X | | | | | | | | |
| Establish User Access Rights | X | | X | | | | | | | | | |
| Create Training Manual | X | X | X | | | | | | | | | |
| Develop Test Plans | | | | | | | | | | | | |
| Conduct Unit Testing | | | | | | | | | | | | |
| Conduct Integration Testing | | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Installation | | | | | | | | | | | | |
| Train Users | X | X | X | X | X | X | | | | | | |
| User Acceptance Testing | | | | | | | | | | | | |
| Modify and Fine-Tune System | | | | | | | | | | | | |
| Data Migration | | | | | | | | | | | | |
| Launch ERP System | | | | | | | | | | | | |
| Plan Resources to Provide Support | | | | | | | | | | | | |
| Parallel Runs Test | | | | | | | | | | | | |
| Detect and Record Anomalies | | | | | | | | | | | | |

If there are any deficiencies, please describe them:

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

Do you have any suggestions for improvement?

…………………………………………………………………………………………

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## Task 7:  Specify each type of resource for each ERP project sub-activity

(*Please apply an X in the relevant box below to indicate the requirement of a resource type for a project sub-activity.  Input the number of resources required in brackets next to the "X".)*

| | Required | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sub-Activity** | **Functional Consultant** | **Technical Consultant** | **Functional Subject Matter Expert** | **Technical Subject Matter Expert** | **Process Owner** | **Key User** | **Account Manager** | **External Project Manager** | **Internal Project Manager** | **Systems Administrator** | **Trainer** | **Project Auditor** |
| Develop Work Plan | | | | | | | | | | | | |
| Assemble Steering Committee and Project Manager | | | | | | | | | | | | |
| Define Project Goals, Scope and Implementation Approach | | | | | | | | | | | | |
| Allocate Resources | | | | | | | | | | | | |
| Clarify Implementation Scope | | | | | | | | | | | | |
| Define Implementation | | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strategy | | | | | | | | | | | | |
| Build AS-IS model | | | | | | | | | | | | |
| Analyse Current Business Processes | | | | | | | | | | | | |
| Identify Existing Gaps | | | | | | | | | | | | |
| Investigate ERP Functionalities | | | | | | | | | | | | |
| Identify Need for Business Process Re-Engineering/Customization | | | | | | | | | | | | |
| New Process Design Mapping | | | | | | | | | | | | |
| ERP Acquisition | | | | | | | | | | | | |
| Hardware Acquisition/Upgrade | | | | | | | | | | | | |
| Build System Prototype | | | | | | | | | | | | |
| Pilot Each Process Design | | | | | | | | | | | | |
| Create Forms and Reports | | | | | | | | | | | | |
| Configure System | | | | | | | | | | | | |
| Perform Data Cleansing | | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Develop Conversion Programs | | | | | | | | | | | | |
| Develop Interface Prpgrams | | | | | | | | | | | | |
| Establish User Access Rights | | | | | | | | | | | | |
| Create Training Manual | | | | | | | | | | | | |
| Develop Test Plans | | | | | | | | | | | | |
| Conduct Unit Testing | | | | | | | | | | | | |
| Conduct Integration Testing | | | | | | | | | | | | |
| Installation | | | | | | | | | | | | |
| Train Users | | | | | | | | | | | | |
| User Acceptance Testing | | | | | | | | | | | | |
| Modify and Fine-Tune System | | | | | | | | | | | | |
| Data Migration | | | | | | | | | | | | |
| Launch ERP System | | | | | | | | | | | | |
| Plan Resources to Provide Support | | | | | | | | | | | | |
| Parallel Runs Test | | | | | | | | | | | | |
| Detect and Record | | | | | | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anomalies | | | | | | | | | | | | | |

If there are any deficiencies, please describe them:

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

Do you have any suggestions for improvement?

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

**Task 8: Please give your opinion on whether the duration for each ERP project sub-activity should be specified as one value (number of days) or as three values; minimum number of days, maximum number of days, and most likely number of days. The first instance uses a one-point estimate, and the second is a three-point estimate. The latter caters for uncertainty.**

………………………………………………………………………………………………

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**Task 9: Please use the space below to provide your opinion on whether a default duration for each ERP project sub-activity should be implemented in the model**

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

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## A.3 Refinement of Complexity Dimensions and Types

| **Aim** |
|---|
| The aim of this document is to refine the ERP implementation complexity dimensions which will be implemented in the ERP Complexity Costing Model. The refinement will be conducted by scoring the suggestions and comments that were made in the questionnaire which was filled out in the first validation session for the complexity dimensions. |

**Researcher:** Aisha Momoh

**Supervisors:** Dr. Essam Shehab, Professor Rajkumar Roy

**Date:**

Name of Participant:………………………………………………………….

Organisation:……………………………………………………………….

Role:………………………………………………………………………..

Industry:…………………………………………………………………….

Years of Experience in Project Management:………………………………..

Project Management Experience in the following areas:

(*Please tick the relevant boxes*)

ERP Project Management ☐

IT/IS Project Management ☐

ERP Implementation Experience in the Following Solutions:

(*Please tick the relevant boxes*)

SAP ☐ Other ☐ *if other, please specify:*…………………..

ORACLE ☐

**<u>Meaning of comment ID (e.g., CDT.B1.1)</u>**

**CDT** means Complexity Dimensions and Types

**B1** means Part B of the questionnaire used to validate the ERP Complexity Costing concept and the first part of the refinement exercise

The number at the end of the ID is a unique number for each comment

*Please read each comment below and score as required.*

### CDT.B1.1. Proposal for Change Management as Complexity

(*Please use the scores below to express your opinion on the comment presented below the score table. Draw a circle around the score most applicable. Please use the space provided below for any additional comments you may have.)*

| Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly Agree |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

It is proposed that Change Management be treated as a complexity instead of incorporating it in the ERP project methodology. Adding it to the project methodology will require associated subactivities. Besides, change management is run as a separate project from the ERP implementation project by some organisations. Although both projects are run concurrently.

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……………………………………………………………………………………………

**CDT.B1.2. Proposal for Steering Committee as Complexity**

(*Please use the scores below to express your opinion on the comment presented below the score table. Draw a circle around the score most applicable. Please use the space provided below for any additional comments you may have.)*

| Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly Agree |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

It is proposed that the cost of the steering committee (for the ERP implementation which is being processed in the model) should not be accounted for, as this is usually a business cost and not an ERP project cost. However, it should be accounted for as a complexity.

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**General Comments**

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…………………………………………………………………………………………

…………………………………………………………………………………………

## A.4 Validation of the Complexity of Resource and Assessment Costing Tool (C-REACT)

Researcher: Aisha Momoh
(a.momoh@cranfield.ac.uk)
Supervisors: Dr. Essam Shehab, Prof. Rajkumar Roy

**A. GENERAL**

1. Name of Participant:…………………………………………………………
2. Organisation:………………………………………………………………………
3. Industry:……………………………………………………………………………
4. Role:…………………………………………………………………………………

5. Years of experience (in ERP project management and complexity assessment):………………………………………………………………………

**B. CASE STUDY OVERVIEW**

1. Case study description

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

2. Information available

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

**C. LOGIC**

1. How logical are the complexity concept and features in the framework (tick the applicable number)?

<table>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td></tr>
<tr><td>Totally Unsuitable</td><td colspan="4">Suitable with critical defects</td><td colspan="4">Suitable with insignificant defects</td><td>Totally Suitable</td></tr>
</table>

Please describe any defects you may have observed:

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

2. How logical are the WBS concept and features in the framework (tick the applicable number)?

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

Please describe any defects you may have observed:

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

3. Is the framework suitable for the needs identification stage of the whole life cycle?

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

If it is not totally suitable, please explain the reason:

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

4. Can the framework be applied in alternative stages to the needs identification stage?

Yes ☐ No ☐

If yes, please specify which stage:

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

**D. GENERALISABILITY**

1. Please comment on how generalisable the framework is within your industry

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

2. Please comment on how generalizable the framework is for other industries
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………

**E. RESPONSIBILITY**

1. How should the framework be used across the ERP industry (e.g., only ERP adopting organisation, or with the consultancy and/or ERP vendors)?
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………

2. What function or unit should have ownership or responsibility of the model within the organisation?
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………

3. How could the owner of the framework maintain it?
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………

**F. BENEFITS OF USING THE FRAMEWORK**

1. How would the framework benefit the needs identification team?
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………

2. How would the framework benefit complexity considerations?

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

**G. LIMITATIONS OF THE FRAMEWORK**

1. What are the potential challenges in using and implementing the tool?

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

2. What are the potential organisational limitations and challenges that arise in using the tool?

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

3. How could the experience of people using the tool affect the output?

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

**H. USABILITY OF THE SOFTWARE TOOL**

1. Assessment of the usability of the tool in terms of features
   a. What are the strongest features?

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

   b. What are the weakest features?

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

2. Assessment of the tool in terms of terminology
   a. How clear and appropriate are the terminologies in the framework?

   ………………………………………………………………………………………

   ………………………………………………………………………………………

   ………………………………………………………………………………………

   Please suggest possible improvements

   ………………………………………………………………………………………

   ………………………………………………………………………………………

   ………………………………………………………………………………………

3. Does the tool provide sufficient information to guide the user?

   Yes ☐ No ☐

   If no, please explain:

   ………………………………………………………………………………………

   ………………………………………………………………………………………

   ………………………………………………………………………………………

4. Evaluate the time required to populate the tool for implementation on a project

   ………………………………………………………………………………………

   ………………………………………………………………………………………

   ………………………………………………………………………………………

5. Please assess the following aspects in the tool:
   a. Layout
   b. Use of colour
   c. Ease of navigation

d. Level of intuition

6. Is the tool flexible enough to be applied with different levels of information availability?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

## I. FRAMEWORK ASSESSMENT

Please assess the completeness/suitability of the framework for the following questions

a. The dimensions and types of complexities

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Incomprehensive | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Comprehensive |

If it is not totally comprehensive, please explain the reason:

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

b. The work breakdown structure activities and resources

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Incomprehensive | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Comprehensive |

If it is not totally comprehensive, please explain the reason:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

c. Applying a three-point estimate in specifying the duration for each activity

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

If it is not totally suitable, please explain the reason:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
………………………

d. Calculating the uncertainty score by averaging the scores across the three NUSAP matrix criteria (basis of estimate, rigour of assessment and validation)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Incomprehensive | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Comprehensive |

If it is not totally comprehensive, please explain the reason:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

e. The technique applied in deriving the complexity weight through analytical hierarchy processing

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

If it is not totally suitable, please explain the reason:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

f. Deriving the complexity level by selecting the relevant criteria

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

If it is not totally suitable, please explain the reason:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

g. Calculating the complexity score by multiplying the complexity weight by the complexity level

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

If it is not totally suitable, please explain the reason:

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

h. The provided set of cost drivers

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Incomprehensive | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Comprehensive |

If it is not totally comprehensible, please explain the reason:

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

i. The mapping of cost drivers to complexity types

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

If it is not totally suitable, please explain the reason:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

j. The provision of a complexity correlation matrix

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

If it is not totally suitable, please explain the reason:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

k. The provision of a WBS complexity classification matrix

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

If it is not totally suitable, please explain the reason:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

l. The suggested distributions for the cost drivers

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Incomprehensive | Suitable with critical defects | | | | Suitable with insignificant | | | | Totally Comprehensive |

| | | | |
|---|---|---|---|
| | | defects | |

If it is not totally comprehensible, please explain the reason:

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

m. The number of distributions produced using Monte Carlo

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Incomprehensive | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Comprehensive |

If it is not totally comprehensible, please explain the reason:

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

n. Applying an uncertainty percentage as contingency in the presence of a high complexity in a critical path activity

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Totally Unsuitable | Suitable with critical defects | | | | Suitable with insignificant defects | | | | Totally Suitable |

If it is not totally suitable, please explain the reason:

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

## J. AGENT-BASED MODEL ASSESSMENT

1. What are the key benefits of the agent-based approach?

   …………………………………………………………………………………………

   …………………………………………………………………………………………

   …………………………………………………………………………………………

2. How suitable is the agent-based approach for ERP resource cost estimating

   …………………………………………………………………………………………

   …………………………………………………………………………………………

   …………………………………………………………………………………………

3. What are the limitations of the agent-based approach?

   …………………………………………………………………………………………

   …………………………………………………………………………………………

   …………………………………………………………………………………………

4. How reliable are the results?

   …………………………………………………………………………………………

   …………………………………………………………………………………………

   …………………………………………………………………………………………

5. How applicable is the approach?

   …………………………………………………………………………………………

   …………………………………………………………………………………………

   …………………………………………………………………………………………

## K. RESULTS

1. Evaluation of the output from the tool based on data from the case study

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

2. Evaluation of the repeatability of the tool based on data from the case study

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

# Appendix B : Complexity and Cost Driver Definitions

## B.1 Definitions for Complexity Dimensions, Complexity Types and Associated Cost Drivers

This appendix presents the definition for each complexity dimension, and describes its relationship with its complexity factors and their associated cost drivers.

**1. Business Process Complexity**

Tarn *et al.* (2002) caution that the complexity of system process does not only involve purchasing a software package, but it is rather an extensive and complex business process. The business processes of an organisation define the way in which an organisation runs its operations on a daily basis. These processes always exist in a company, irrespective of whether there is a system or not, and regardless of whether or not, they have been properly defined. However, what is for certain is that business processes must be defined for implementation in an ERP solution. Consequently, they are known as TO-BE processes. The more processes that are being implemented by an organisation, the more complex the ERP solution will be, especially as they are implemented in modules and they affect the integration in the system and the business as a whole.

Kim (2009) states that it is well known that business processes should be reengineered or reformed according to best practices during the ERP implementation. The reengineering process requires redesigning business processes and activities and monitoring performance of the redesign (Kim, 2009)

Business processes are usually presented in diagrammatic form. These diagrams can be complex, thereby making it difficult for both stakeholders and programmers to understand (Hamilton *et al.,* 2013). However, this complexity can be avoided in order to provide simpler diagrams which are easier to understand and will provide a clearer description for the programmers who will implement the system which will automate the business processes (Hamilton *et al.,* 2013). As complexity can affect maintainability and understandability of business processes, it is essential to maintain a low complexity (Hamilton *et al.,* 2013).

Tarn *et al.,* (2002) conclude that an imperative hidden cost often incurred by organisations implementing ERP is the loss of efficient process due to an inability to automate their business processes. Very often, ERP vendors offer an ERP package as a solution to making an organisation more efficient without first looking at the corporate business processes (Tarn *et al.,* 2002). Consequently, automating an inefficient process would only generate more problems and unnecessary spending.

Business process complexity is indicated by and made up of two complexity types; (1) clarity of existing process which defines the cost drivers required to establish the degree to which the business processes are understood and clear – a common ERP implementation success factor is the development of a clear definition of business processes and requirements (Momoh *et al*., 2010; Al Mashari *et al.,* 2003; Mabert *et al.,* 2003; Wagner *et al.,* (2004), and (2) business process standardisation which specifies the amount of business process already embedded in the underlying ERP model, to be implemented. The complexity types and cost drivers for business process complexity dimension are depicted in Figure B.1-1.

The cost drivers for clarify of existing process are; roles, information, level of automation, definition, documentation, performance, and controls. And the cost driver for business process standardisation complexity type is the number of standard business processes.

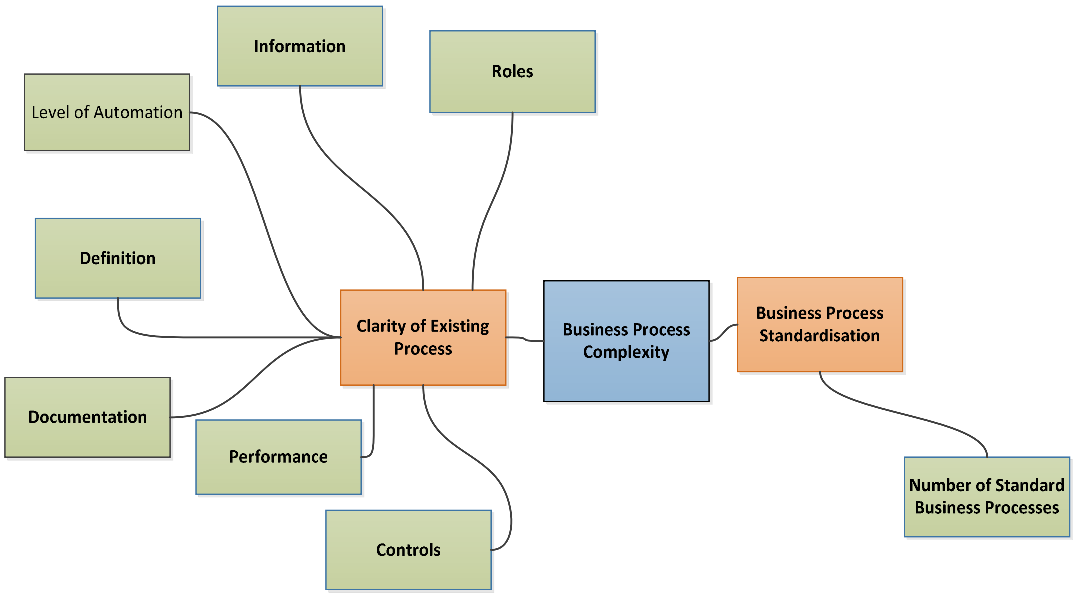


**Figure B.1-1:** Business Process Complexity Types and Cost Drivers

### 2. Customisation Complexity

Customisation refers to the modification of the underlying functionality of an ERP solution. This action is a deviation from standard functionality and usually involves enhancing a standard program. Typically, customisation is a crucial, lengthy and costly process, as emphasised in Chapter 2. According to Honglei *et* al. (2009), complexity metrics can help to evaluate the workload of programming and cost of development. In certain instances, businesses must change the system to accommodate some of its processes (Yusuf *et al*, 2004). However, this could become a severe challenge when the level of customisation is high, and when the type of customisation affects the integration of other processes and the modules in the system. Therefore, a high level of customisation will yield a high level of complexity. Furthermore, the relationship between the complexity and size of the program is non-linear (Honglei *et al.*, 2009). In Figure B.1-2, the relationships between customisation complexity and its associated complexity types and cost drivers are depicted.

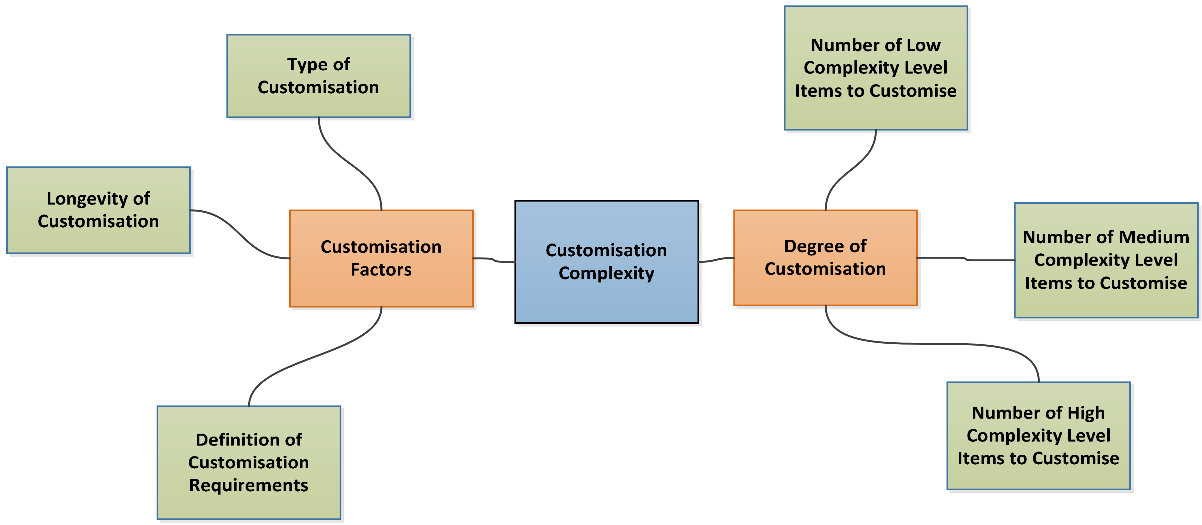


**Figure B.1-2:** Six Aspects of Software Complexity

Customisation constitutes two types of complexity, customisation factors and degree of customisation. Customisation factors can be measured with the cost drivers type of customisation, longevity of customisation and definition of customisation requirements. In terms of the degree of customisation complexity type, its complexity and cost will be measured using the cost drivers number of low complexity level items to customise, number of medium complexity level items to customise, and number of high complexity level items to customise.

### 3. Data Cleansing and Conversion Complexity

Prior to generating and distributing ERP management reports, the data contained in the reports must firstly be created, and this can be a costly and inefficient process (Yusuf *et al.,* 2004). Therefore, it is essential to assure the integrity of the data which is migrated into the ERP solution. Cleansing and converting data to be transferred to an ERP system are complex tasks. Data cleansing involves reviewing all the data in the legacy system in relation to the data which will be used in the TO-BE (future) ERP solution, and ensuring that there are no anomalies in the data. In other words, all the impairment in the data must be eliminated prior to transferring it to the new system. Migrating the data to the new system will firstly entail converting the data fields of the data in the old system to the new fields in the new system. This is a laborious undertaking. In the event that several legacy systems exist from which data should be extracted from, conversion can last a very long time. A high amount of data requires extra effort to cleanse and convert. Furthermore, a system with low data integrity will result in a very high complexity. The cost of data cleansing and conversion is often underestimated, hence it has been reported as one of the ERP hidden costs in the literature review of this thesis. The types of complexity and associated cost drivers for data cleansing and conversion are illustrated in Figure B.1-3.

The contributing types of data cleansing and conversion complexity are; (1) interface size which is made up of the three cost drivers, number of low complexity level interfaces, number of medium complexity level interfaces, and number of high complexity level interfaces, (2) quality of data which is determined by the seven cost drivers, corporate master data management effectiveness, number of low complexity level conversions, number of medium complexity level conversions, number of high complexity level conversions, quality of old (legacy) data, number of items to cleanse, and number of data interrelationships, and (3) integration of legacy system which has only one cost driver of the same name. The majority of difficulties experienced by ERP implementations have been the costly development of additional software to help ‘bridge’ or retrieve information from legacy systems (Yusuf *et al*., 2004). Hence it is imperative to assess and cost the complexity of this task beforehand.

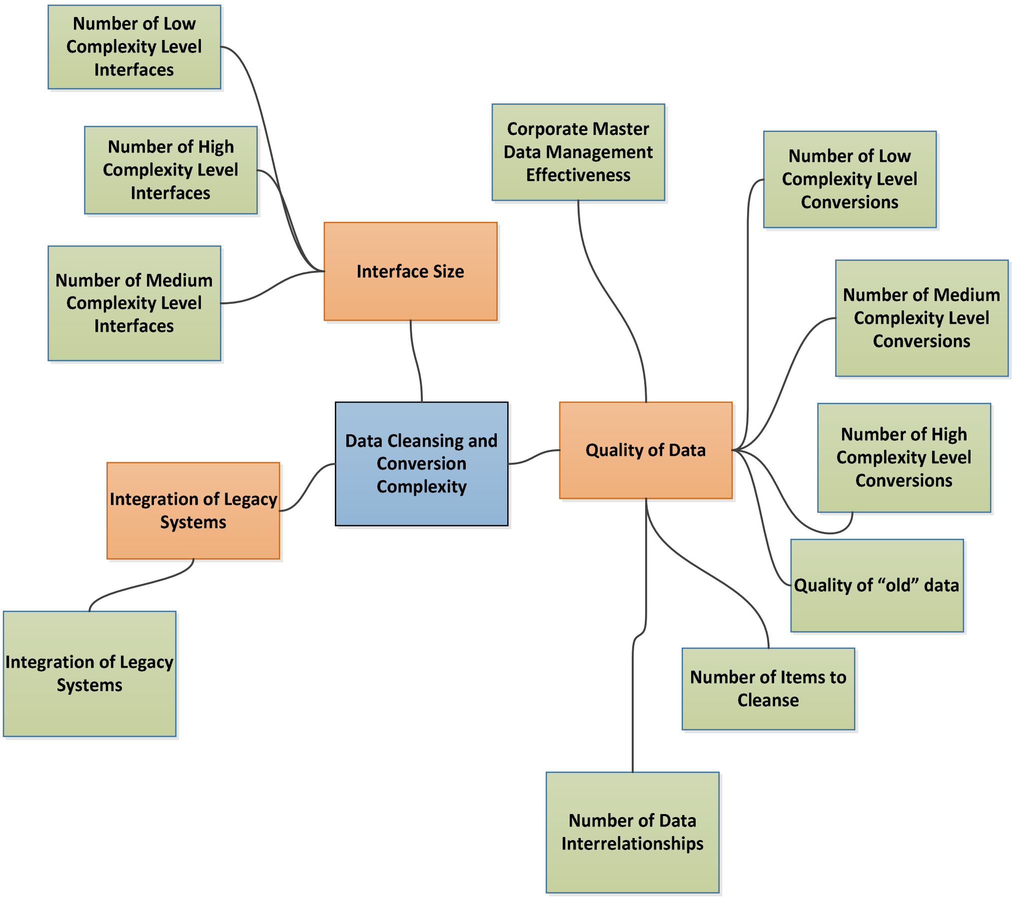


**Figure B.1-3:** Data Cleansing and Conversion Complexity Types and Cost Drivers

## 4. External Resource Complexity

In addition to a high cost and corporate time, the implementation of ERP systems requires resources (Rajnoha *et al.,* 2014). One of the critical success factors for an ERP implementation is the availability of experienced resources as discussed in Chapter 2 of this thesis. Deloitte Consulting (2007) assert that a lack of required skills and experience hinders efforts to overcome complexity. In order to achieve high-level communication with each client and be able to resolve conflicts that may probably arise, a consultant should be particularly skilled (Maditinos *et al.,* 2012). A successful consultant possesses both sufficient technical background, as well as the ability to communicate knowledge and experience, in a way that he gains the client's trust (Chen and Wang, 2006; Maditinos *et al.,* 2012). Due to the complex nature of ERP systems, Chen and Wang (2006) and Maditinos *et al.* (2012) advise that every ERP adopting company must acquire the adequate know-how and understanding of the system in order to fully exploit its potential. Consultant support from specialists who know in detail the ERP system and have the experience of how the system operates is crucial in order to achieve the required knowledge transfer to the company (Chen and Wang, 2006; Maditinos *et al.,* 2012).

Utilising inexperienced resources in an ERP project often has a ripple effect on the rest of the project and causes a project failure due to the complexities introduced. In the event that an organisation commissions inexperienced external resources to configure an ERP solution, the system will be poorly configured. This will affect the TO-BE (future) business processes and integration. It will also have an adverse effect on reporting. The success of an ERP implementation is reliant on external resources, to a large extent because they are perceived by the adopting organisation as competent and knowledgeable. Most of the activities in a project is assigned to external resources. The unavailability of experienced resources creates a series of complexities in an ERP implementation, some of which are mentioned above.

The external resource complexity is influenced by three complexity types; (1) onshore/offshore/rightshore which is a measure for determining the location of work conducted by the ERP implementation project team as this is a substantially contributing factor to the complexity and cost of the project, (2) level of experience, and (3) total team size. The level of experience complexity type is exactly the same name as its one cost driver which enables the complexity measure and subsequent costing of the competence of the project team. The team's level of experience will determine whether or not, the implementation will be successful. A high level of project ERP implementation and methodology experience within the project team may reduce the implementation complexity, but will increase its cost. On the other hand, a low or medium level of experience in the project team will increase both complexity and cost. The onshore/offshore/rightshore complexity type has the same name as its cost driver. In the event that an organisation uses an onshore model in their ERP implementation, it means that their project is outsourced to a consultancy which is located in the same country. This model is usually quite costly, but rarely presents a culture or language barrier, as the project resources are expected to speak the same language as the ERP adopter. A cheaper model is that of offshore which means that the project is operated in a foreign country where a different language is spoken. Hence a majority of ERP implementation projects today employ the services of offshore resources. A rightshore model on the other hand, is a balance between offshore and onshore. Each model possesses its own complexities in terms of language, culture, and cost. A language barrier may impede effective communication, thereby reducing the pace of the project implementation and introducing schedule overruns.

The third complexity type, level of experience is measured by the cost drivers; industry-specific experience of the project team, number of implementation cycles the project team members have been involved in, experience of the current ERP version and relevant module for implementation, proven implementation methodology used by the project team on previous projects, and a proven methodology toolset applied by the project team on previous projects.

**5. Organisational Readiness Complexity**

According to Yusuf *et al.* (2004), an organisation must assess itself to see if it is ready for ERP. It is important for any organisation to be ready for a new system to be deployed in the organisation. If an organisation is not ready for a new application, the project is likely to fail; conveying and defining business processes and requirements will be inaccurate, data cleansing will not be effective, training will be poor as employees will resist change, and ultimately, the organisation will suffer operationally, culturally and financially. When a business is unprepared for an ERP project, complexities in the project are triggered.

There are two complexity types which influence organisational readiness; external readiness and organisational readiness.

The external readiness complexity is measured by two cost drivers; (1) regulatory impact which assesses new legislation and its effect on the implementation, and (2) external stakeholder readiness which evaluates the degree of ERP system acceptance by external business partners. An example of new legislation could be a new tax rule imposed by the government which must be incorporated in the ERP solution. This type of complexity is emergent because it is not always expected. The kind and volume of impact which is imposed on an ERP project by new legislation is wholly dependent on the scale and type of regulation being introduced by government. But what is certain is that the project complexity will increase as more resources might be required to configure the new rules in the system, and the new rules might impede other areas of the system and develop other emergent complexities. The effect of this complexity will be a schedule overrun and cost increase. In terms of the external stakeholder readiness cost driver, this could mean that an external business partner is not ready for the implementation for a number of reasons. An example of this is that the ERP adopter might have a supplier who needs to implement a system which will be interfaced into the new ERP system to enable automated purchase orders, invoicing and information on deliveries. In the event that this system is not available before ERP is in operation, the ERP adopter might be forced to conduct procurement manually, or search for a new supplier. Either way, there is likely to be a time and cost overrun because of the complexities introduced.

The organisational readiness complexity type constitutes four cost drivers; (1) the adopting organisation’s experience with complex information systems, (2) the business-as-usual (BAU) support team readiness which measures whether or not the organisation has a team in place to take over the system from the consultant, once it is in operation, (3) degree of buy-in from business which assesses the level of acceptance of the new ERP system by the future users of the system as well as whether the implementation is led by IT or the business – resistance to change is one of the common ERP challenges reported by Wagner *et al*. (2004), and (4) "what's in it for me" which is an assessment of how much incentive is in the stakeholder management plan to indicate recognition of the users of the system as a key group. The BAU team is composed of the members of the adopting organisation supporting the users of the ERP system. Apparently, familiarisation of users with the new system is not an easy task and involves tenacity and patience from the users (Maditinos *et al.,* 2012; Chen and Wang, 2006). Therefore, users may not be motivated to support the ERP system in that they are not willing to cooperate with the consultants and assimilate the knowledge transferred to them (Maditinos *et al.,* 2012; Chen and Wang, 2006). The types of complexity and associated cost drivers for organisational readiness are illustrated in Figure B.1-4.

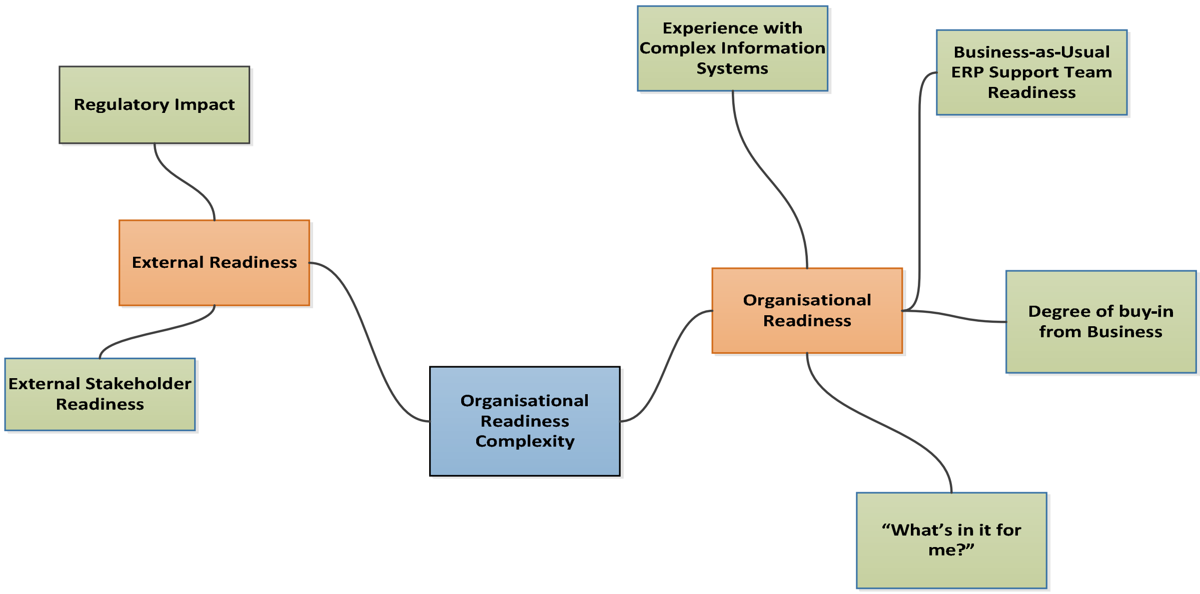


**Figure B.1-4**: Organisational Readiness Complexity Types and Cost Drivers

### 6. System Configuration Complexity

It is hard to comprehend the complexity of an ERP implementation project, especially when ERP software is a semi-finished product that requires only configuration and no programming (Bansal *et al*., 2008). However, it turns out that configuration process for a simple application has very high complexity (Bansal *et al*., 2008). Poor configuration of an ERP solution introduces complexity and the consequence of this is an increase in the overall complexity in the system. As complexity is exponential, the complexity caused by poor configuration will most likely result in other emergent complexities. An increase in configuration which occurs during implementation, results in an increase in cost. The complexity of ERP software is because of the underlying data, their interaction and process complexity (Bansal *et al*., 2008, Uflacker *et al*., 2007).

The complexity types which effect system configuration are degree of configuration, test strategy and hardware/corporate policies. The test strategy complexity is measured by the cost driver availability of automated tools (e.g., Loadrunner, QTP), the degree of configuration is measured by the number of items to configure, and the seven cost drivers which measure the hardware/corporate policies are the deployment approach of the hardware, the assessment of whether the client is thick or thin, the software version used in the hardware, the location of the hardware in terms of whether it is on the cloud or the premises of the organisation, the cost of the hardware (if on premise), hardware SLA (Service Level Agreement) – uptime, hardware SLA – resilience, and hardware SLA – backups.

### 7. Internal Resource Participation Complexity

However competent a consultant may be, ERP implementation will not run smoothly unless the members of the client (top management and users) organisation are committed to the adoption and the use of the ERP system (Chen and Wang, 2006; Maditinos *et al.,* 2012). It is extremely crucial to involve internal staff in an ERP implementation, especially the best resources in the organisation. This ensures a good definition of the business processes to be implemented in the new ERP solution, and effective data cleansing. Otherwise, external resources would be left to learn the business (which is time consuming) and implement the business processes. This is detrimental to the business in the sense that the external resource may not have an indepth understanding of the business operations, especially if they come from a systems background, and not a business background.

Deloitte Consulting (2007) emphasise that a key challenge for many organisations is finding the internal capabilities to bot manage and improve their technology environment.

The complexity experienced in internal resource participation is triggered by the complexities in culture, process owner support and team members. Each of these three complexity types is measured by cost drivers.

The cost drivers for culture is organisational culture which assesses whether the organisation has accepted the change to a new system. In terms of the complexity type process owner support, it is measured by three cost drivers; (1) SME (Subject Matter Expert) availability which assesses how much time will be spent on the project by the SMEs, (2) process owner availability which measures how much time is spent on the project by the process owner – Wagner *et al.* (2004) claim that organisational complexity can affect the ability to integrate the many departments in an organisation and identify a process owner, and (3) sponsor strength which evaluates the amount of involvement in the project by the executive team. The SME is a domain expert in the organisation and imparts their knowledge of the business processes in their function to the consultants. A process owner is responsible for a part of the end-to-end process which will be implemented in the ERP system. The executive team is composed of top management in the ERP adopting organisation. Top management support describes the extent to which the members of the executive team provide the attention, resources, and authority required for ERP implementation (Chen and Wang, 2006; Maditinos *et al.,* 2012). Top management support is a prerequisite for the successful implementation of ERP systems (Maditinos *et al.,* 2012). Chen and Wang (2006) and Maditinos *et al.* (2012) assert that top management has the responsibility to align the new ERP system with the current business practices and prepare the employees for the change introduced by the new technology.

The team members complexity type is assessed by four cost drivers; percentage of time for internal resource, change management experience, ERP implementation experience, and incentivisation.

### 8. Module Complexity

Modules enable the functions in an organisation. According to Yusuf *et al.* (2004), functions are defined as actual physical tasks that are performed within a company, whilst modules may be considered as pieces of software that help to provide the functions. An increase in the number of modules can lead to more work, and most likely, more business processes. According to Honglei *et al.* (2009), an increase in module complexity results in an increase in the effort required to test and maintain the modules, An increase in the number of components in a system triggers an increase in complexity, effort and cost. Furthermore, the modules in an ERP solution are integrated and the essence of this is to accomplish business integration. If the integration is impaired by customisation or overloaded with business processes, the integration facilities could fail. Uflacker *et al*.(2007) report that interdependency between modules is boosted with an increase in process integrity and automation, thereby contributing to system complexity. The mindmap for linking module complexity with its associated types and cost drivers is presented in Figure B.1-5.

The module complexity constitutes two types, module maturity and inter-module integration. Module maturity is assessed by three cost drivers; numbers of large/medium sized customers using the module, years (number of) since initial deployment, number of changes since last module upversion (or upgrade), and reliability and maintainability.

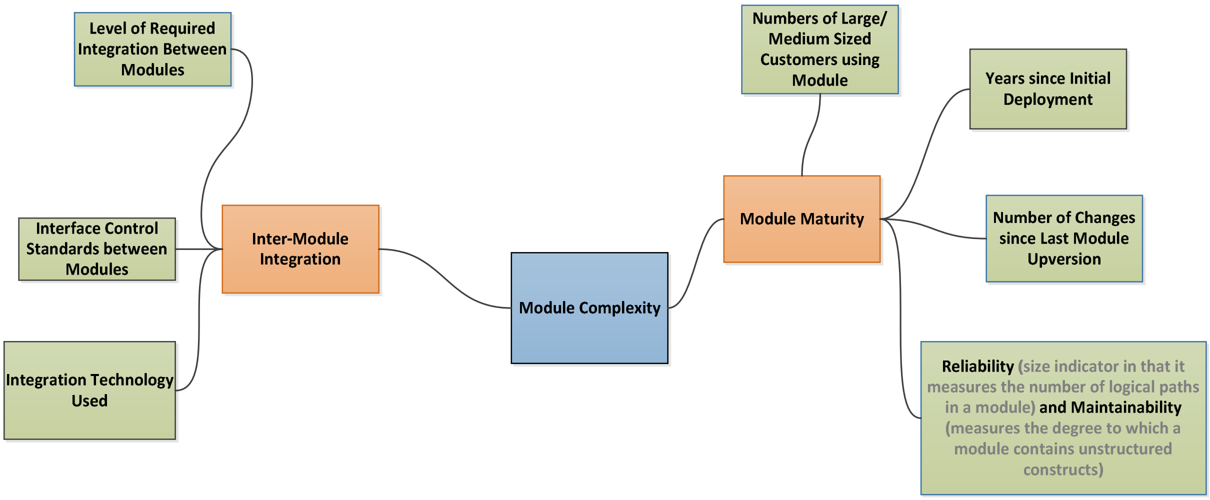


**Figure B.1-5:** Module Complexity Types and Cost Drivers

The cost drivers for evaluating the inter-module integration are level of required integration between modules, interface control standards between modules, and integration technology used.

### 9. User Complexity

The number of users whom will utilise an ERP solution in its production state determines the software license fee, number of users for training, types of role which will be configured in the solution, and the method by which the users will access the system. A high number of users will require a substantial amount of training facilities and equipment, which will be fulfilled through a higher degree of organisation. Also, a high number of roles will lead to increased configuration of the system. The mindmap for linking the user complexity dimension with its various types and associated cost drivers is illustrated in Figure B.1-6.

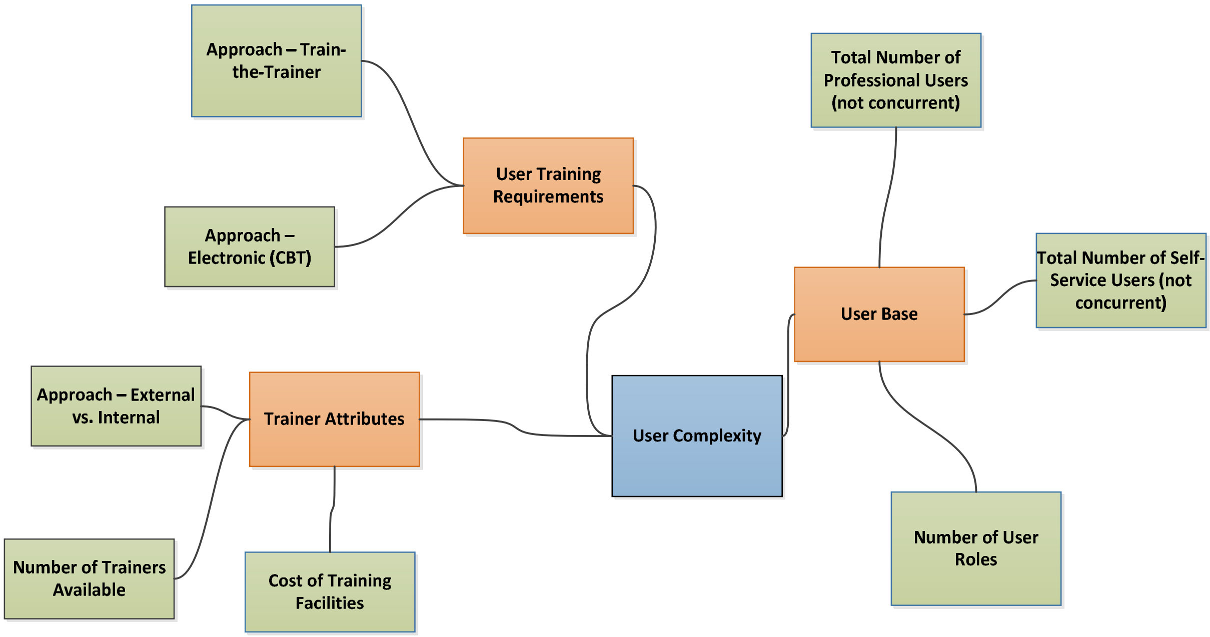


**Figure B.1-6:** User Complexity Dimensions with Complexity Types and Cost Drivers

There are three types of user complexity which are the user base, user training requirements, and trainer attributes.

The cost drivers for trainer attributes are cost of training facilities, training approach – external versus internal, and number of trainers available. In terms of the user base complexity type, it is assessed by the number of user roles, total number of self-service users (not concurrent), and total number of professional users (not concurrent). And finally, the cost drivers for user training requirements are approach – train-the trainer and approach – electronic (CBT).

**10. Project Control Complexity**

The project control complexity dimension covers a variety of areas in an ERP implementation. It focuses on the team, the governance of the project and the technical aspects of the project in terms of managing the changes to the configuration and development of the ERP system.

The types of complexity associated with project control are leadership, team attributes and technical scope.

Each project control complexity type is associated with cost drivers for measurement of complexity and cost. The technical scope complexity is assessed by the number of standard items to change and the number of non-standard items to change. Secondly, the cost drivers for measuring the complexity and cost of the team attributes are assumption management, team language, and team working environment/geography. And thirdly, the cost drivers for measuring the leadership complexity are business changes, governance approach, and changes in senior management during project. The presence of changes to the business, for instance, an acquisition, will impede the progress of the ERP implementation by introducing complexities like change of employee terms and conditions, and adding new human resource terms and conditions to the ERP configuration. Another potential complexity is to develop interfaces into and out of the systems of the acquired company. Also, changes in senior management during the project may result in implementation instability. This will definitely increase the complexities in the system, thereby triggering an increase in cost.

**11. External Factors Complexity**

The external factors complexity dimension is concerned with the complexities inherent in government legislation and any industry self-regulation that may affect the dynamics, operations or structure of the organisation as a whole. This dimension also covers the exchange rate and its effect on the project currency.

Regulation and exchange rate are the two complexity types which trigger the overall project control complexity. Deloitte Consulting (2007) advise that regulatory compliance requires the modern day chief information officer (CIO) to remain aware of both new and existing regulation, and must simultaneously ensure that the IT environment is compliant with international, country-specific, and industry-specific legislation. Deloitte Consulting (2007) further state that regulatory compliance is often treated as a stand-alone implementation rather than as part of a strategic restructuring of IT assets, thereby leading to increased complexity.

The cost driver for measuring the complexity of regulation is the likelihood of additional regulation, and the cost driver for evaluating the complexity of the exchange rate is the project currency in relation to whether it is a sterling or non-sterling project in an economically and politically stable or non-stable country.

## B.2 Taxonomy of Cost Drivers

The developed taxonomy of cost drivers implemented in this research is outlined in Table B.2-1.

| Cost Driver | Quantitative | Qualitative | Direct Influence | Indirect Influence |
|---|---|---|---|---|
| **Number of standard business processes** | • | | • | |
| **Number of low complexity level items to customise** | • | | • | |
| **Number of medium complexity level items to customise** | • | | • | |
| **Number of high complexity level items to customise** | • | | • | |
| **Number of low complexity level interfaces** | • | | • | |
| **Number of medium complexity level interfaces** | • | | • | |
| **Number of high complexity level interfaces** | • | | • | |
| **Number of items to cleanse** | • | | • | |
| **Number of data interrelationships** | • | | • | |
| **Number of low complexity level conversions** | • | | • | |
| **Number of medium complexity level conversions** | • | | • | |
| **Number of high complexity level conversions** | • | | • | |
| **Number of items to configure** | • | | • | |
| **Number of standard items to change** | • | | • | |

| Cost Driver | Quantitative | Qualitative | Direct Influence | Indirect Influence |
|---|---|---|---|---|
| Number of non-standard items to change | • | | • | |
| Total number of professional users (not concurrent) | • | | • | |
| Total number of self-service users (not concurrent) | • | | • | |
| Number of user roles | • | | • | |
| Roles | | • | • | |
| Information | | • | • | |
| Definition | | • | • | |
| Performance | | • | • | |
| Controls | | • | • | |
| Documentation | | • | • | |
| Level of automation | | • | • | |
| Industry-Specific experience | | • | | • |
| Number of implementation cycles | • | | | • |
| Experience of this version and module of ERP | | • | | • |

| Cost Driver | Quantitative | Qualitative | Direct Influence | Indirect Influence |
|---|---|---|---|---|
| **Proven implementation methodology** | | • | | • |
| **Proven methodology toolset** | | • | | • |
| **Onshore/Offshore/Rightshore** | | • | | • |
| **Total team size** | • | | | • |
| **Type of customisation** | | • | • | |
| **Longevity of customisation** | • | | | • |
| **Definition of customisation requirements** | | • | • | |
| **Integration of previous systems** | | • | • | |
| **Quality of “old” data** | | • | • | |
| **Corporate master data management effectiveness** | | • | | • |
| **Deployment approach** | | • | | • |
| **Thick/Thin client** | | • | | • |
| **Software versions (java, IE, chrome, etc.)** | | • | | • |
| **Cloud vs. On-Premise** | | • | | • |

| Cost Driver | Quantitative | Qualitative | Direct Influence | Indirect Influence |
|---|---|---|---|---|
| Hardware cost (if on premise) | • | | • | |
| Hardware SLA – uptime | | • | | • |
| Hardware SLA – resilience | | • | | • |
| Hardware SLA – backups | | • | | • |
| Availability of automated tools (loadrunner, QTP, etc.) | | • | • | |
| Approach - train-the-trainer | | • | | • |
| Approach - electronic (CBT) | | • | | • |
| Approach - external vs. internal | | • | | • |
| Number of trainers available | • | | | • |
| Cost of training facilities | • | | | • |
| Experience with complex information systems | | • | | • |
| Business-as-Usual ERP support team readiness | | • | | • |
| Degree of buy-in from business | | • | | • |
| What's in it for me? | | • | | • |

| Cost Driver | Quantitative | Qualitative | Direct Influence | Indirect Influence |
|---|---|---|---|---|
| External stakeholder readiness | | • | | • |
| Regulatory impact | | • | | • |
| Changes in senior management during project | | • | | • |
| Governance approach | | • | | • |
| Business changes | | • | | • |
| Assumption management | | • | | • |
| Team working environment/geography | | • | | • |
| Team language | | • | | • |
| Organisation culture | | • | | • |
| SME availability | | • | | • |
| Process owner availability | | • | | • |
| Sponsor strength | | • | | • |
| %time for internal resource | • | | | • |
| Incentivisation | | • | | • |

| Cost Driver | Quantitative | Qualitative | Direct Influence | Indirect Influence |
|---|---|---|---|---|
| Change management experience | | • | | • |
| ERP implementation experience | | • | | • |
| Numbers of large/medium sized customers using module | • | | | • |
| Years since initial deployment | • | | | • |
| Number of changes since last module upversion | • | | | • |
| Reliability (size indicator in that it measures the number of logical paths in a module) and maintainability (measures the degree to which a module contains unstructured constructs) | • | | | • |
| Level of required integration between modules | | • | | • |
| Interface control standards between modules | | • | | • |
| Integration technology used | | • | | • |
| Likelihood of additional regulation | | • | | • |
| Project currency | | • | | • |

**Table B.2-1**: Developed Taxonomy of Cost Drivers

# Appendix C : Definition of Developed WBS Activities

The description for each developed ERP project activity is provided in Table C-1.

| ERP Implementation Project Activity | Project Activity Description |
|---|---|
| **Define Project Goals, Scope and Implementation Approach** | The goals for the project, its scope and approach adopted for implementation are defined. The main tasks of this activity are:<br>1. Appoint Key Senior Sponsor<br>2. Develop Business Case<br>3. Assemble Steering Committee, Project Manager and other key stakeholders<br>4. Create Strategy, Approach and Plan for resources to provide support<br>5. Clarify implementation scope<br>6. Define implementation strategy<br>7. Review Project Mobilisation<br>8. Establish Business and Process Governance<br>9. Establish Framework for Quality<br>10. Define Business Readiness Approach |
| **Define Change Management Scope, Approach and Baseline Measures** | The items which will be addressed in change management, along with its scope and method of application are defined. Also, the method employed for measuring milestones is defined. The key tasks of this activity are:<br>1. Analyse Stakeholders for Change<br>2. Create Project Name<br>3. Evaluate Change Impact<br>4. Develop Action Plan for Change Management<br>5. Develop Communications Plan<br>6. Develop Stakeholder Engagement Strategy<br>7. Define Training Approach |

| | |
|---|---|
| **Define Strategy and Standards for Architecture and Infrastructure** | The strategy which will be used to deploy the systems, servers and their connections for enabling the ERP implementation is defined. The standards which must be adhered to as a result of policy are also agreed upon. The main tasks of this activity are:<br>1. Review Infrastructure<br>2. Establish Data Strategy and Approach<br>3. Create Data Management/Migration Strategy and Plan<br>4. Select Data Management/Migration Tools<br>5. Define Technical Approach and Standards |
| **Develop Work Plan** | The project plan is drawn up and agreed upon. High level estimates are also provided as part of this activity. The budget is approved in this activity. |
| **Allocate Resources** | Internal staff required to 462elevant462te in the project, as well as external consultants are agreed upon and allocated to their various tasks and schedules. |
| **Identify Benefits and Develop Benefits Realisation Model** | The benefits which would be yielded by the ERP adopting organisation as a result of implementing ERP, will be evaluated and defined. Furthermore, the method by which the benefits will be realised will be defined as a model. This model will also enable the organisation to verify and measure benefits realised. |
| **Plan for Design** | A project plan is defined for the design of the ERP solution. The project plan alon with progress reports are also reviewed. |
| **Analyse Business Process** | The current business processes in the organisation are studied and analysed and designed. The tasks entailed in this activity are:<br>1. Analyse current business processes<br>2. Identify existing gaps<br>3. Investigate ERP functionalities<br>4. Identify need for business process re-engineering/customization<br>5. New process design mapping<br>6. Document Blueprint |

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|---|---|
| **Setup Data Environment and Tool** | This activity entails assessing and setting up the environment where the organisational data exists, and identifying the tools which would be used for migrating the data. The data is also assessed for whether it is would be available for transfer to the new system at the appropriate time. The procedure for data definition and transfer is also defined in this activity. The tasks in this activity are:<br>1. Assess Data Readiness<br>2. Define Data Structure<br>3. Establish Data Governance |
| **Define Approach to Manage Roles** | The user access rights are defined in this activity, as well as the approach and strategy employed to manage these access rights. The tasks in this activity are:<br>1. Design User Access Rights<br>2. Update Blueprint |
| **Define RICEFW** | The items for development are defined in this activity. Afunctional specification is defined for each development item. The acronym RICEFW stands for reports, interfaces, conversions, enhancements, forms and workflows. |
| **Establish Detailed Design for Architecture** | The detailed design for deploying the ERP architecture is defined. |
| **Develop Test Plans and Strategy** | The test strategy for the business processes and RICEFWs implemented is ascertained. Also the test scenarios and test plans are agreed upon. |
| **ERP Acquisition** | The ERP software and hardware required for installation of the software are purchased and acquired. |
| **Create Sandbox and Development Environment** | An environment for configuring the business processes and developing the RICEFW items is created within the system installed. |
| **Perform Systems Administration for Blueprint** | The systems administration for the design activities commences with this activity. |
| **Define Metrics for Business** | The metrics for measuring the project milestones are defined. |
| **Engage Stakeholders and** | In this activity, the Change Manager engages the stakeholders |

| | |
|---|---|
| **Change Agents** | of the implementation in the project. The members of staff whom will act as change agents for transforming the business, will be selected in this activity. |
| **Define Detailed Communications Plan** | A plan for communicating the milstones and implementation progress to the organisation is defined. The tasks fulfilled are:<br>1. Communicate Solution for Awareness<br>2. Assess Change Impact<br>3. Define Business Readiness Approach |
| **Create Training Needs Analysis** | The training templates are created. Also, the processes which will be implemented are assessed in order to establish the users of the processes who will require training in using the TO-BE ERP system. |
| **Assess Benefits** | The benefits anticipated for realisation are evaluated. |
| **Manage Blueprint** | The blueprint phase is managed. The tasks entailed in this process are:<br>1. Finalise Blueprint and Detailed Estimates<br>2. Review Blueprint<br>3. Review Project Plan and Create Progress Reports<br>4. Prepare for Realisation |
| **Perform Systems Administration for Realisation** | The systems administration for the implementation continues into the realisation phase. |
| **Build System Prototype** | A high level set of business processes are built into the ERP solution and demonstrated to the stakeholders. |
| **Configure System** | The established business processes are configured in the ERP solution. |
| **Create Forms, Reports, Enhancements and Workflows** | Development of the forms, reports, enhancements and workflows for which functional specifications is fulfilled. The technical specifications for these items are also defined. |
| **Build User Access Rights** | Development of the user access rights which have been defined, is accomplished in this activity. |

| | |
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| **Perform Data Cleansing** | The data required to run the processes configured in the system is cleansed by the organisation to enable a streamlined transfer to the ERP solution. The tasks in this activity are:<br>1. Document Technical Specification for Conversion programs<br>2. Execute Data Readiness<br>3. Prepare for Final Prep Phase Data Testing |
| **Develop Data Conversions** | The fields which are required for converting the current data to the data in the new system are defined. The conversion programs are also built and the technical specifications are documented. |
| **Develop Interface Programs** | Programs are developed to enable the interfacing of systems into and out of the new ERP system. The technical specifications are also documented. |
| **Conduct Unit Testing** | Each item which has been configured and developed is tested individually. The final test plans are also documented. |
| **Prepare to Deliver Training** | A draft training manual is created for delivering training to the users of the new ERP system. |
| **Create QA Environment** | In order to enable a collective testing of all the configured and developed items across the relevant modules, a testing environment in the ERP system is created. The acronym QA stands for Quality Assurance. |
| **Manage Realisation** | The realisation activity is managed from the beginning of the phase to the point of creating a QA environment. The tasks fulfilled in this activity are:<br>1. Review Project Plan and Create Progress Reports<br>2. Review Realisation<br>3. Finalise Realisation<br>4. Prepare for Final Preparation |
| **Perform Systems Administration for Final Preparation** | Administering the system for the final preparation activity commences here. Although this activity spans the implementation from the point of the first systems administration activity in the Blueprint phae. |

| | |
|---|---|
| **Conduct Integration Testing** | The entire system is collectively tested for integration. |
| **Train Users** | The final version of the training manual is created, and the users of the ERP system are trained accordingly. |
| **Conduct User Acceptance Testing** | The tasks in this activity are:<br>1. Train UAT (User Acceptance Testing) Team<br>2. Support UAT/Modify and Fine-Tune System |
| **Sign off Benefits** | The benefits which are achieved so far are ratified. |
| **Make Go/No-Go Decision** | At this point of the implementation, the business makes a decision as to whether to proceed to a live environment with the ERP solution or not. A live environment will enable the ERP adopter to use the system. The readiness of the organisation to begin use of the system is assessed. |
| **Prepare Business for Go-Live** | Preparing the business to begin utilising the ERP system in a live environment entails the following:<br>1. Prepare Business for Cutover<br>2. Manage Approach for Transition<br>3. Create Migration Trial Loads<br>4. Support Realisation Phase Data Testing<br>5. Plan for Data Cutover<br>6. Assess and Report Change Readiness<br>7. Implement Communications Plan<br>8. Communicate Change Essence for Understanding<br>9. Communicate Business Support for Change<br>10. Assess and Report Stakeholder Effectiveness<br>11. Enable Benefits<br>12. Assess Business Readiness |
| **Create Production Environment** | The live system is installed. |
| **Data Migration and Validation** | The cleansed and tested data is transferred to the live ERP system. |
| **Launch ERP Functionality/System** | The new ERP system is launched and the stability of the system is monitored. |

| | |
|---|---|
| **Parallel Runs Testing** | In a project where the Payroll module is implemented, the payroll processing in the new ERP system is tested simultaneously with that in the old system. This process is crucisl as it entails the payment of employees' salaries. Hence, in the event that it is flawed in the new system, the organisation can fall back on the old system and make the 467elevant corrections to the new system. The parallel run continues for the number of payroll periods agreed until the organisation is confident that the new system will calculate the correct payments, the Finance General Ledger will record the correct payments and the bank transfer of payments will be efficiently and correctly conducted. |
| **Manage Final Preparation** | Management of the final preparation involves the following:<br>1. Review Project Plan and Create Progress Reports<br>2. Mobilise Go-Live Support Team |
| **Perform Systems Administration for Go-Live** | The system administration of the ERP solution continues into the go-live phase of the implementation if the organisation decides to go live in the new ERP system environment. |
| **Conduct Cutover Activities** | Activities to enable a proper cutover to the new system are fulfilled as follows:<br>1. Load Post-Go-Live Data<br>2. Reinforce Change Communication |
| **Assess Data Quality** | Quality of the data transferred to the new ERP system is assessed. |
| **Detect and Fix Anomalies** | In the event that anomalies exist, they are detected and resolved. The solution is improved. |
| **Re-assess, Learn and Improve (RLI)** | This activity entails the following tasks:<br>1. Assess Learning<br>2. Assess and Measure Effectiveness of Solution on Business<br>3. Communicate Achievement from Change<br>4. Evaluate Change Programme<br>5. Review Go-Live<br>6. Review Project Plan and Create Progress Reports<br>7. Review State of Solution |

| | |
|---|---|
| **Handover Solution to Business** | The new ERP solution is handed over to the new support team known as BAU (Business As Usual) for management and support. |
| **Project Closure** | The end of the implementation project is ratified and the organisation begins to prepare for business optimisation. |

**Table C-1**: Developed WBS Project Activity Description

# Appendix D : C-REACT User Guide

This section provides the user guide for the complexity of resource and assessment costing tool.

## 1. Overview

This guide describes a tool which was developed to identify, assess and cost potential enterprise resource planning (ERP) implementation complexities experienced by project resources. The tool is known as Complexity Resource Assessment Costing Tool (C-REACT). It entails processes for the project scheduling of the implementation activities within which the complexities exist, allocation of resources who experience the complexities, complexity identification, uncertainty evaluation for the complexity estimates, complexity assessment, complexity classification and complexity correlation reporting. Scenario analysis may be conducted using the framework by applying different scenarios for a better understanding of the complexities and their impact on the implementation cost. Adapting different scenarios also allows for an understanding of the impact of uncertainty on the complexity cost. In order to automate these processes, three modules have been developed in the tool; (1) Project Scheduling and Resource Allocation, (2) Complexity Assessment, and (3) Dynamic Cost Estimation for Resource Complexity.

In the ERP industry, the essence of C-REACT is to enable a two-fold process (1) a cost estimation process which supports ERP project cost estimation by predicting the cost of ERP resource complexities, and (2) a process to identify, assess and control ERP complexities inherent in the implementation stage. This tool is used in the needs identification stage of an ERP project lifecycle. The estimate will inform an organisation of the potential costs of ERP resources from a complexity perspective, thereby enabling them to make informed decisions on ERP implementation complexity and cost reduction. Knowledge of potential complexities will also aid the elimination of substantial errors during implementation. The next section describes the needs identification stage of an ERP whole life cycle project. An overview of the tool is provided in Figure 1-1.

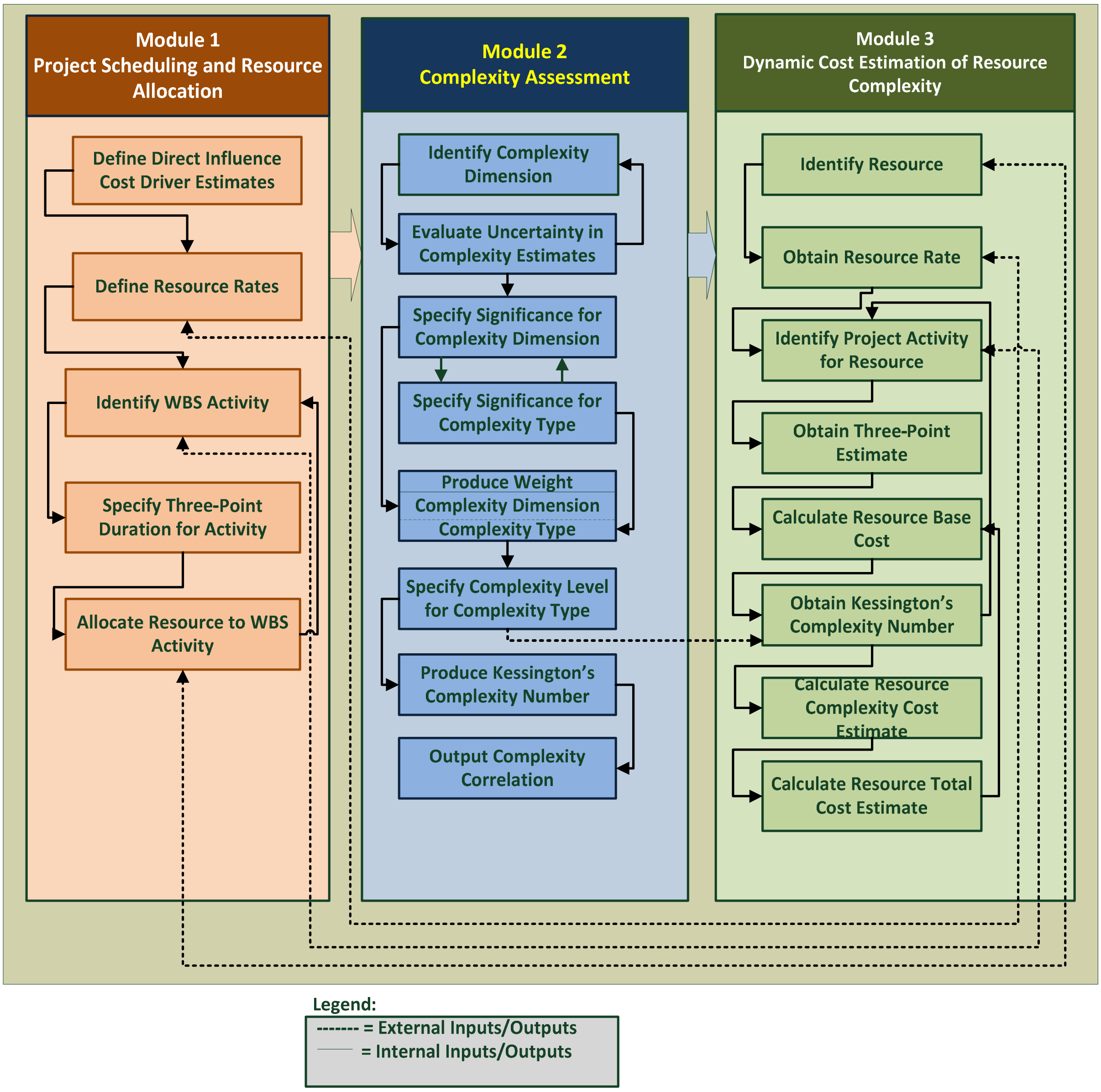



Figure 1-1: Overview of C-REACT

## 2. Complexity Resource Assessment Costing Tool

The Complexity Resource Assessment Costing Tool (C-REACT) is developed using Microsoft Excel for inputting the relevant data by the user, and Agent-Based Modelling (ABM) for simulating the cost estimates.

There are three integrated modules embedded in C-REACT as follows:

- Project Scheduling and Resource Allocation which enables the specification of the relevant WBS elements for the estimating of resource base costs. This module is embedded in Microsoft Excel.
- Complexity Assessment which drives the process of uncertainty evaluation, complexity significance assessment and complexity scoring. The outputs of this process derive a complexity measure for costing. Microsoft Excel is used to develop this module.
- Dynamic Cost Estimation for Resource Complexity which simulates the resource complexity costs through agent-based modelling.

This section provides a guide for the first two modules.

### 2.2 C-REACT Complexity Assessment Process

The entire Complexity Assessment process in C-REACT constitutes the first two modules described above. The first module enables the scheduling of the potential ERP implementation project as well as its resource allocation. And the second module drives the identification and assessment of ERP implementation complexity with an evaluation of its uncertainty.

The Project Scheduling and Resource Allocation module accepts inputs from the user on three different screens:

- direct influence cost driver estimates with inputs:
    - ➢ quantity of direct influence cost driver
- project schedule (using a work breakdown structure) with inputs:
    - ➢ fifty-three activities
    - ➢ fourteen resource types

  - three-point estimate effort for each activity
  - critical path indicator for the relevant activity
- resource profile where the resource rates are specified with inputs:
  - rate for each resource

The functions in this module are as follows:

- the parametric estimator, which calculates a most likely effort for each direct influence cost driver
- the effort calculator in the project schedule screen
- the cost calculator which calculates and outputs the cost of each resource, each activity and the total project in the project schedule

The complexity assessment module accepts inputs on the following screens:

- complexity dimension specification with inputs:
  - complexity dimensions
- uncertainty evaluation for complexity with inputs:
  - uncertainty ranks for complexity dimensions
- significance assessment of complexity dimensions with inputs:
  - significance ranks for complexity dimensions
- complexity type significance assessment with inputs:
  - significance ranks for complexity types
- complexity scoring sheet with inputs:
  - complexity level scoring for each complexity

The above inputs and calculations are enabled by the following functionalities:

- NUSAP pedigree ranking function which is used to evaluate the uncertainty associated with the complexity estimates provided by the user.
- AHP function which is applied in assessing the significance of each complexity against another, and outputs a weight for each complexity.
- Complexity scoring function which enables the user to score each complexity type by its level of complexity

- Complexity classification which produces a final complexity score for each project activity, known as a Kessington's Complexity Number (KCN). The KCN is derived by multiplying the weight of the complexity by its level. KCN is used in module 3 to calculate the complexity cost for each resource. A matrix indicating the KCN for each project activity is also presented.

The architecture is composed of several screens. Each screen contains fields and buttons. The flowchart for the screens is presented in Figure 2.1-1. These screens and their associated fields are described below.

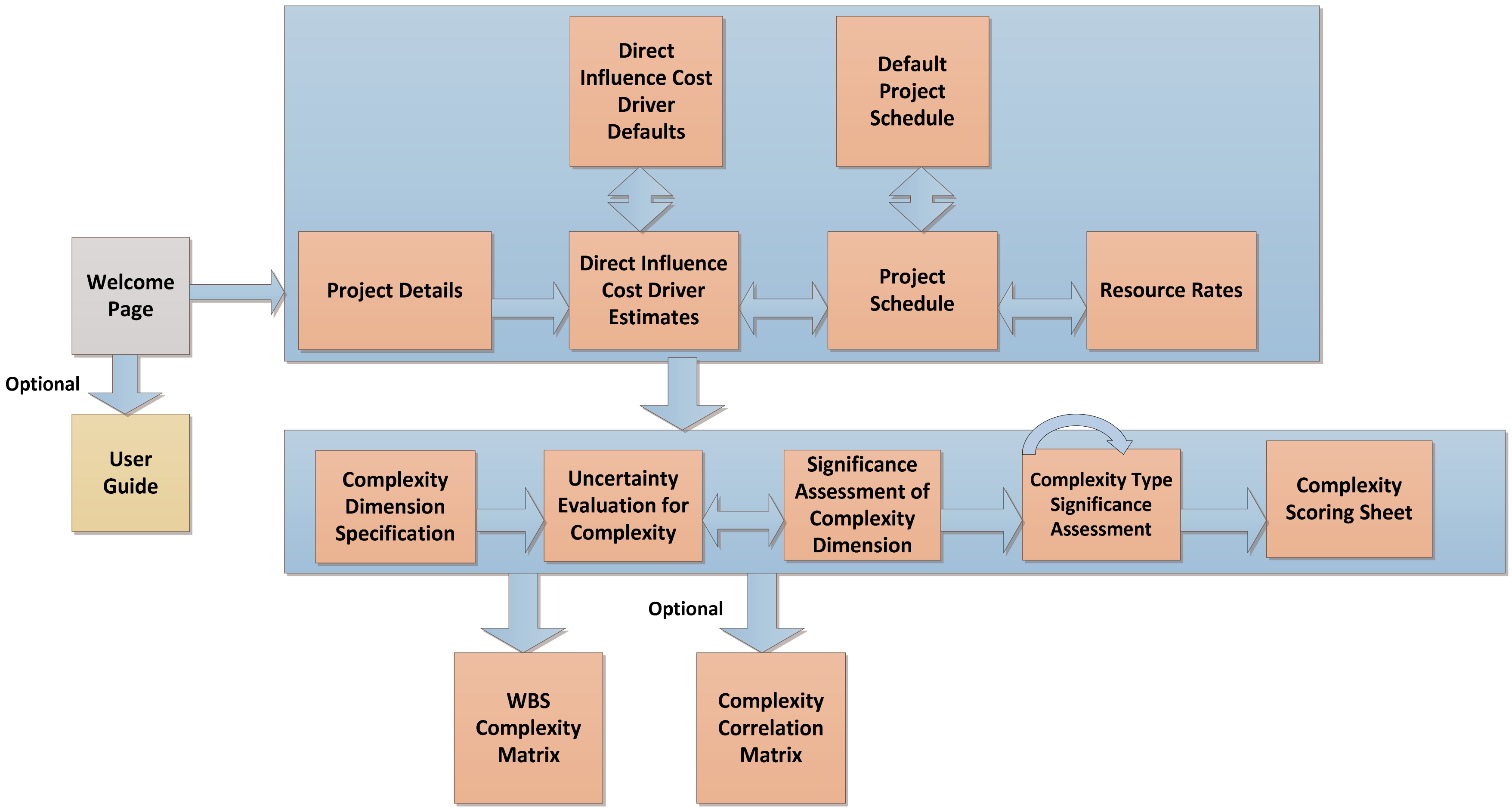



Figure 2.1-1: Flowchart for Complexity Assessment Tool

Two reports are produced as follows:

- A WBS Complexity Matrix indicating the KCN for each project activity
- A Complexity Correlation Matrix illustrating the complexities which may be effected in the event that certain complexities arise

## 1. Welcome Page

This is the main menu (see Figure 2.1-1-1) of the tool. It consists of options which lead to the project scheduling and complexity assessment menus.

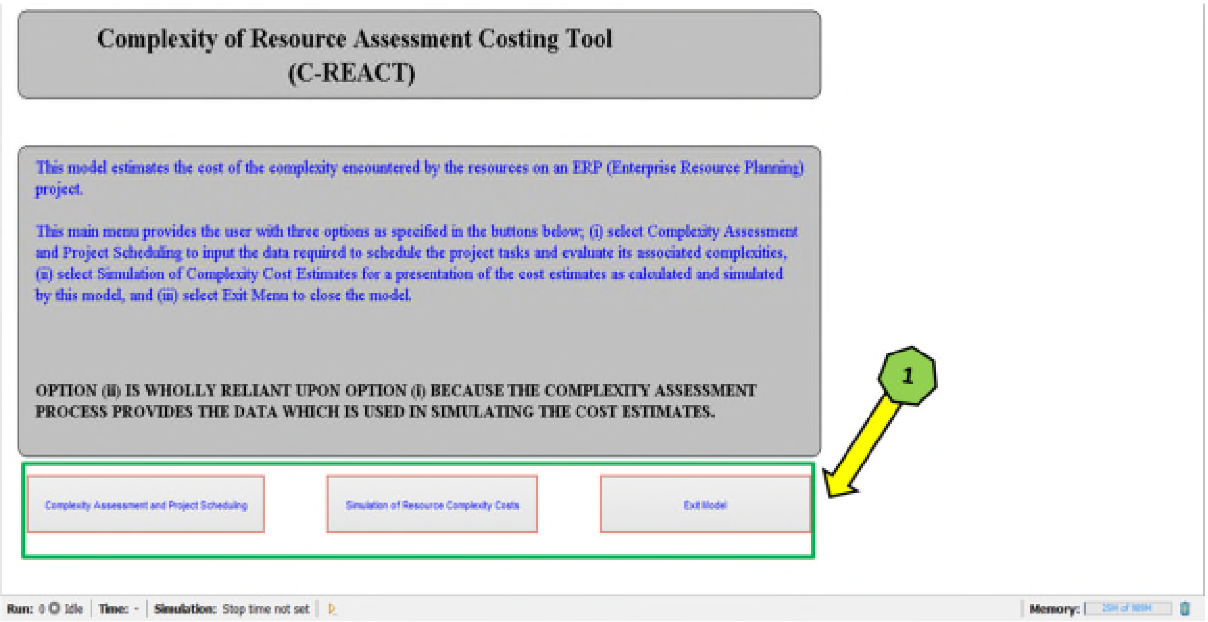



Figure 2.1-1-1: C-REACT Main Menu

The three buttons on this screen labelled **1** are as follows:

- **COMPLEXITY ASSESSMENT AND PROJECT SCHEDULING** which leads to Module 1 and Module 2 of C-REACT
- **SIMULATION OF RESOURCE COMPLEXITY COSTS** which executes Module 3 of C-REACT
- **EXIT MODEL** which exits C-REACT

## 2. Complexity Assessment Tool

This screen is the welcome page of C-REACT Module 1 and Module 2. It contains six buttons, each of which leads the user to other screens. The welcome page is illustrated in Figure 2.1-2-1.

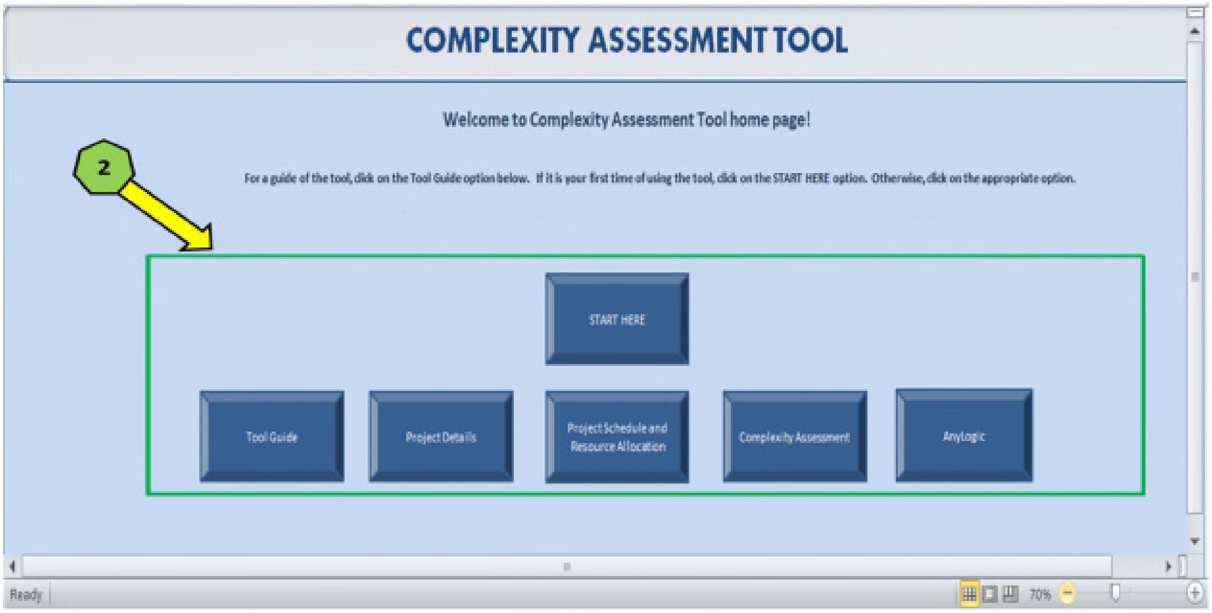



Figure 2.1-2-1: Welcome Page of C-React Complexity Assessment

The buttons labelled **2** are outlined as follows:

- **START HERE** – this takes the user through all the screens which require inputs for both the project scheduling and resource allocation, and the complexity assessment processes.
- **TOOL GUIDE** – this is described in (3)below
- **PROJECT DETAILS** – this is described in (4) below
- **PROJECT SCHEDULE AND RESOURCE ALLOCATION** – this is described in (5) below
- **COMPLEXITY ASSESSMENT** – this is described in (6) below

- **ANYLOGIC** – **this button is *ONLY* selected when the user has concluded the complexity assessment process in Module 1 and Module 2.**

## 3. User Guide

This provides the user with a link to this manual.

## 4. Project Details

This button leads the user to a screen called Project Details which is presented in Figure 2.1-4-1

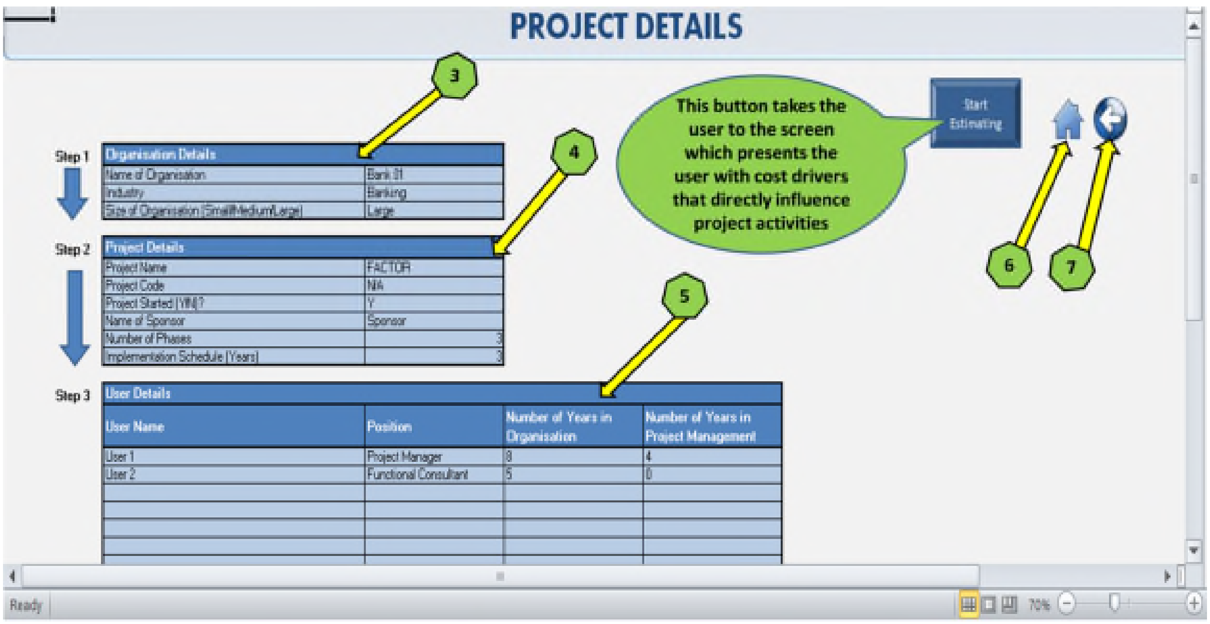



Figure 2.1-4-1: Project Details Screen

This screen prompts the user for their details:

- **3** - Organisational details
  - **Name of Organisation**
  - **Industry**
  - **Size of Organisation**

- 4 - Project details
  - **Project Name**
  - **Project Code**
  - **Project Started (Y/N)**
  - **Name of Sponsor**
  - **Number of Phases**
  - **Implementation schedule (Years)**
- 5 User details
  - **User Name**
  - **Position**
  - **Number of Years in Organisation**
  - **Number of Years in Project Management**

The other two buttons on this screen are:

- 6 – Home button takes the user to the welcome page. This button is presented on every screen.
- 7 – Back button returns the user to the previous screen. This button appears on all screens except for those screens in the Complexity Type Significance assessment process. These screens are created dynamically, depending on the complexity dimensions which are selected by the user. This assessment process is described in (6) below.

**5. Project Schedule and Resource Allocation**

This screen presents three buttons, each leading to a different screen. The screens fulfil the process of the project schedule and resource allocation module The buttons are:

A. **DIRECT INFLUENCE COST DRIVER ESTIMATES**
B. **RESOURCE RATES**
C. **WORK BREAKDOWN STRUCTURE**

## 5A. Direct Influence Cost Driver Estimates

This leads to a screen which presents the rates which would be used to estimate the most likely duration for the activities which the specified cost drivers have a direct influence on. The duration automatically updates the relevant WBS activity and influences the calculation of the pessimistic and optimistic durations. The top section of the screen is presented in Figure 2.1-5A-1.

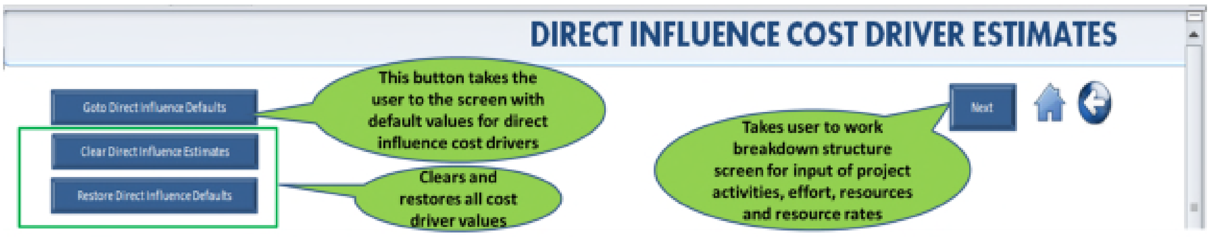



Figure 2.1-5A-1: Top Section of Direct Influence Cost Driver Estimates

The first half of the remaining part of the screen is presented in Figure 2.1-5A-2.

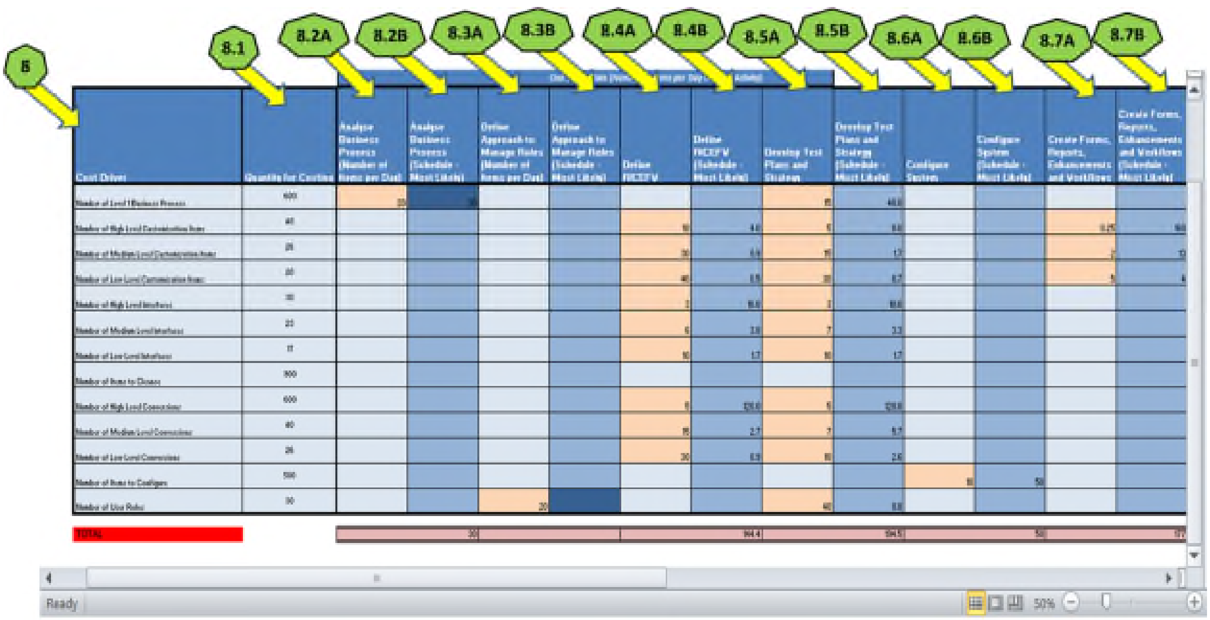



Figure 2.1-5A-2: First Half of Direct Influence Cost Driver Estimates Screen

All the fields on this screen *except* for **Quantity for Costing** are pre-specified and do not require any input from the user. The fields on Figure 2.1-5A-2 are described as follows:

- 8 - **Cost Driver**: these are pre-defined by the industrial collaborators of this research. The items below are specified only where relevant, and each of those specified after quantity for costing represent an activity in the WBS
    - 8.1 - **Quantity for Costing**: this is manually entered by the expert unless they opt to use the defaults in the tool. This is the **ONLY** field which requires input from the user.
    - 8.2A - **Analyse Business Process (Number of Items per Day)**
    - 8.2B - **Analyse Business Process (Schedule – Most Likely)** -calculated schedule based on quantity for costing and number of business processes defined per day
    - 8.3A - **Define Approach to Manage Roles (Number of Items per Day)**
    - 8.3B - **Define Approach to Manage Roles (Schedule – Most Likely)**
    - 8.4A - **Define RICEFW**
    - 8.4B - **Define RICEFW (Schedule – Most Likely)**
    - 8.5A - **Develop Test Plans and Strategy**
    - 8.5B - **Develop Test Plans and Strategy (Schedule – Most Likely)**
    - 8.6A - **Configure System**
    - 8.6B - **Configure System (Schedule – Most Likely)**
    - 8.7A - **Create Forms, Reports, Enhancements and Workflows**
    - 8.7BA - **Create Forms, Reports, Enhancements and Workflows (Schedule – Most Likely)**

The second half of the remaining part of the screen is presented in Figure 2.1-5A-3.


Figure 2.1-5A-3: Second Half of Direct Influence Cost Driver Estimates Screen

The fields on the second half of the screen are:

- **8.8A - Build User Access Rights**
- **8.8B - Build User Access Rights (Schedule – Most Likely)**
- **8.9A - Perform Data Cleansing**
- **8.9B - Perform Data Cleansing (Schedule – Most Likely)**
- **8.10A - Develop Interface Programs**
- **8.10B - Develop Interface Programs (Schedule – Most Likely)**
- **8.11A - Develop Data Conversions**
- **8.11B - Develop Data Conversions (Schedule – Most Likely)**
- **8.12A - Conduct Unit Testing**
- **8.12B - Conduct Unit Testing (Schedule – Most Likely)**
- **8.13A - Conduct Integration Testing**

- **8.13B - Conduct Integration Testing (Schedule – Most Likely)**
- **8.14A - Conduct User Acceptance Testing**
- **8.14B - Conduct User Acceptance Testing (Schedule – Most Likely)**
- **9** – The total most likely duration for each of the activities above

### 5B. Resource Rates

The expert specifies the daily rate for each resource type on the project team. This rate would be used to calculate the resource's cost. The **RESOURCE RATES** screen is presented in Figure 2.1-5B-1.

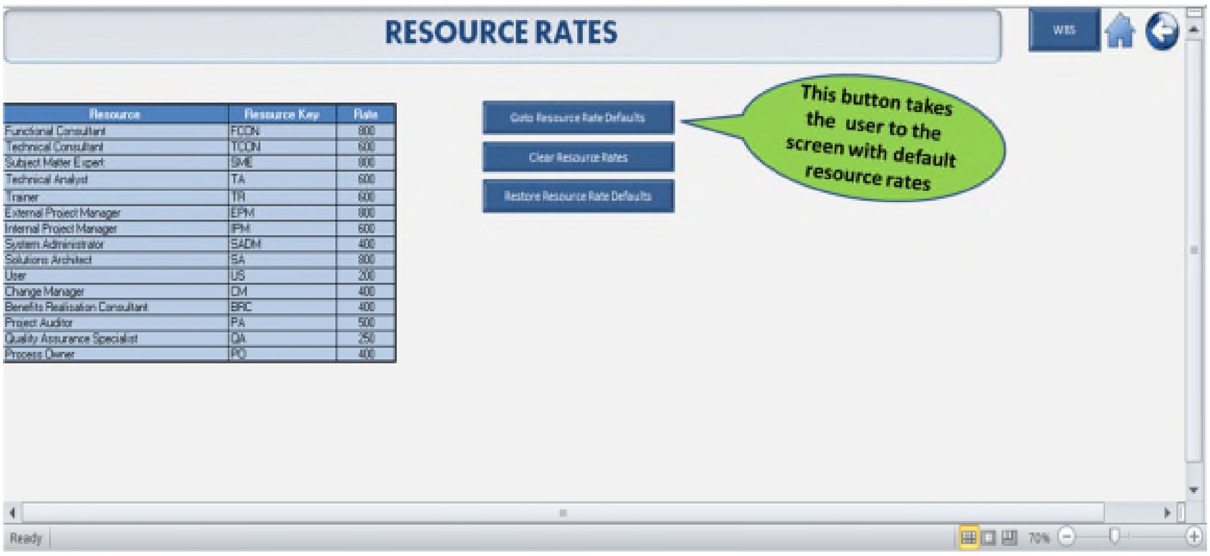



Figure 2.1-5B-1: Resource Rates

### 5C. Work Breakdown Structure (WBS)

This button takes the user to the **PROJECT SCHEDULE** screen. It accepts the user's inputs to specify the project activities, their durations, and resources allocated to the activities. It also outputs the resource and activity cost for each duration. A screenshot of the project schedule overview is presented in Figure 2.1-5C-1. The top part of the screen is presented in Figure 2.1-5C-2.

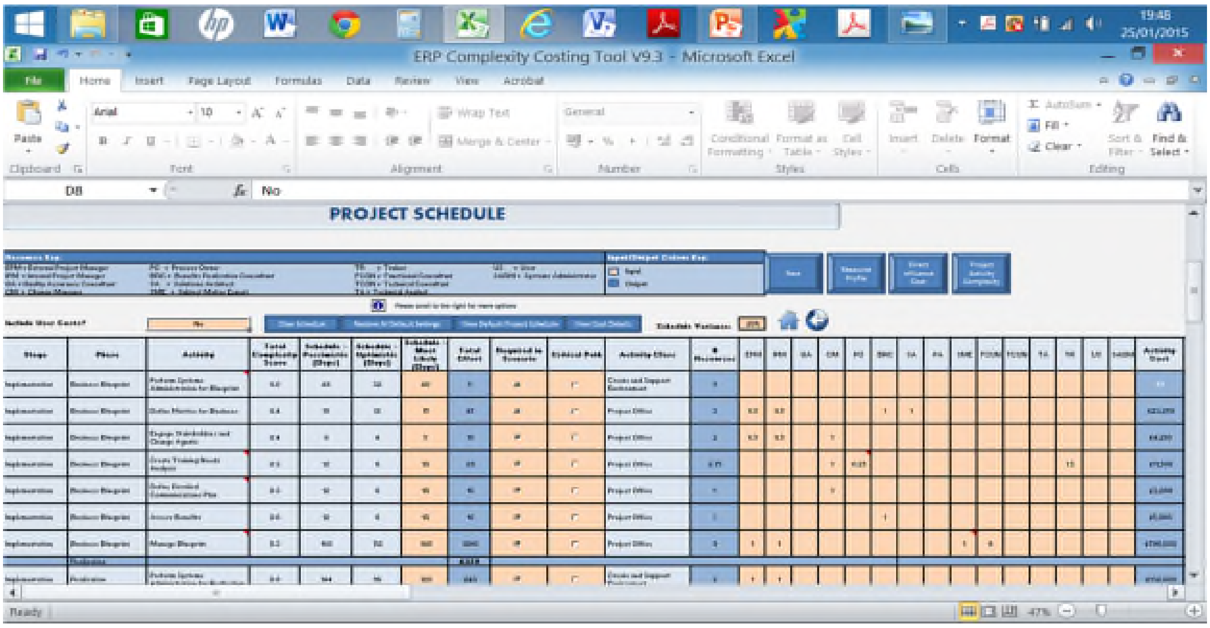



Figure 2.1-5C-1: Project Schedule Screen Overview

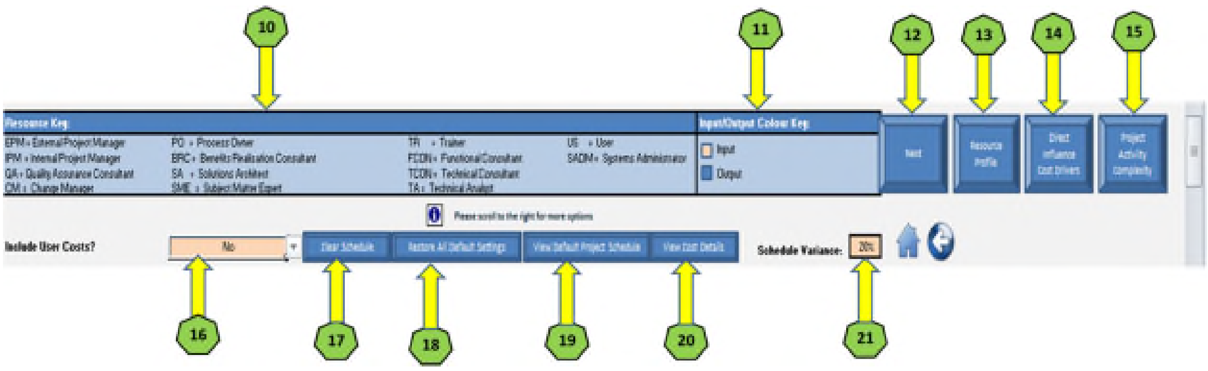



Figure 2.1-5C-2: Top Part of Project Schedule (WBS) Screen

The fields in Figure 2.1-5C-2 are:

- **10** – This palette outlines the description for each of the resources presented in the WBS
- **11** – This palette presents the colour keys which indicate the colour for input values and that for output values

- **16** – This field allows the user to specify either **YES** to include user costs in the total amount of the project, or **NO** to exclude user costs.
- **21** – this is the **SCHEDULE VARIANCE** field which presents a default value of 20% to be added to the most likely duration for each activity.  It also allows the user to input a different number.

The buttons depicted in Figure 2.1-5C-2 are:

- **12** – **NEXT** takes the user to the next screen
- **13** – **RESOURCE PROFILE** presents the user with the **RESOURCE RATES** screen
- **14** – **DIRECT INFLUENCE COST DRIVERS** presents the user with this screen in the event that they wish to change the quantities of elements which have a direct impact on certain activities
- **15** – **PROJECT ACTIVITY COMPLEXITY** takes the user to the WBS Complexity Matrix screen
- **17** – **CLEAR SCHEDULE** deletes all the durations for each activity, and the quantity of each resource in the WBS.
- **18** – **RESTORE ALL DEFAULT SETTINGS** enables the user to apply the default activity durations and resource quantities for the WBS.
- **19** – **VIEW DEFAULT PROJECT SCHEDULE** presents the screen with the default WBS entries which were specified by industrial collaborators for use in C-REACT.
- **20** – **VIEW COST DETAILS** is a calculator which computes and presents the cost of each resource type for each activity.

The second half of the Project Schedule screen is illustrated in Figure 2.1-5C-3.  This part of the screen constitutes the stage, phase, activity, total complexity score, activity duration, total effort, flag to select activity, flag to specify activity in critical path, activity class, total resource quantity, quantity of each resource for each activity, and total activity cost.

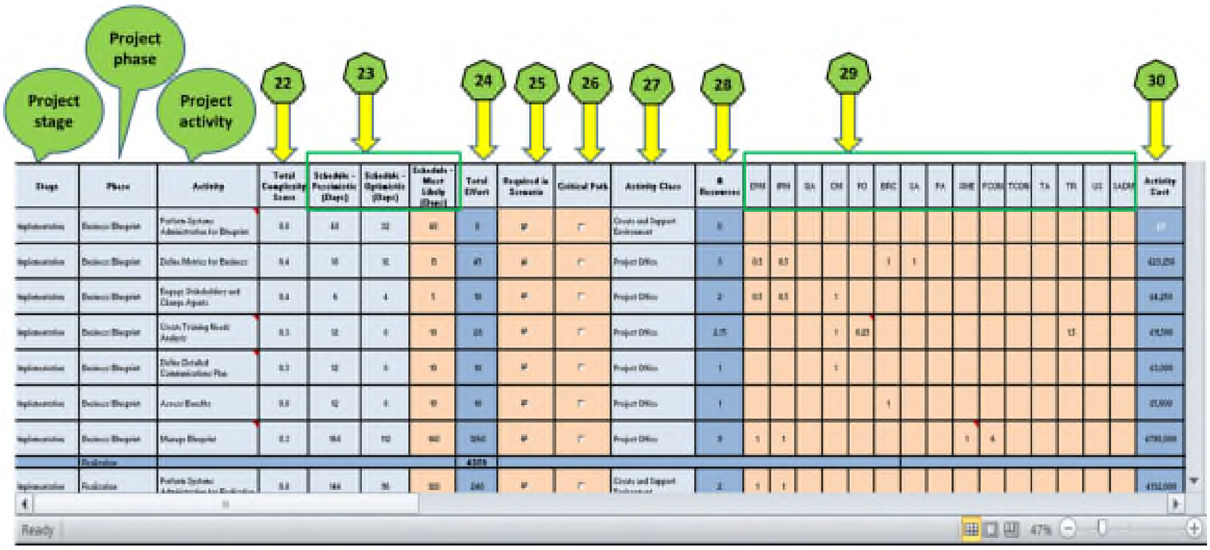



Figure 2.1-5C-3: Second Part of Project Schedule Screen

The fields on this screen are:

- **Stage** which represents the whole life cycle stage. C-REACT addresses only one stage which is the ERP Implementation stage.
- **Phase** – there are five phases:
  - ➢ Project Preparation
  - ➢ Business Blueprint
  - ➢ Realisation
  - ➢ Final Preparation
  - ➢ Go-Live
- **Activity** – there are fifty-three activities in C-REACT and a list of all these activities with their descriptions are provided on the notes for the relevant activities in the WBS.
- **22** - **Total Complexity Score** displays the complexity score for each activity. It is only displayed when the expert returns to the WBS after complexity assessment.

- 23 - Schedule represents three-point estimates specifying the duration for each activity
    - **Schedule - Pessimistic (Days)**
    - **Schedule – Optimistic (Days)**
    - **Schedule – Most Likely (Days)**
- 24 - **Total effort** calculates the total effort of all the resources working on the relevant activity
- 25 - **Required in Scenario** – this is a tick box for each activity which enables an expert to specify which activity is included in the costing scenario
- 26 - **Critical Path** – this is a tick box for each activity which enables the expert to specify which activity is in the critical path of the project. In the event of a high complexity in the relevant activity, an additional cost is added to the complexity cost for the respective resources in this activity.
- 27 - **Activity Class** – the industrial collaborators requested for groupings of activities into classes for high level filtering and reporting for management
- 28 - **#Resources** is the total number of resources for the relevant activity
- 29 **-** Each of the next 15 columns indicates the resource types and quantity of each of these resources allocated to the relevant activity:
    - **EPM** – External Project Manager
    - **IPM** – Internal Project Manager
    - **QA** – Quality Assurance Specialist
    - **CM** – Change MAnager
    - **PO** – Process Owner
    - **BRC** – Benefits Realisation Specialist
    - **SA** – Solutions Architect
    - **PA** – Project Auditor

- **SME** – Subject Matter Expert
- **FCON** – Functional Consultant
- **TCON** – Technical Consultant
- **TA** – Technical Analyst
- **TR** - Trainer
- **US** - User
- **SADM** – Systems Administrator

- 30 - **Activity Cost** displays the cost for each activity
- **Total Phase Cost** displays the cost for each phase

**6. Complexity Assessment**

This is a submenu which presents buttons enabling the user to select screens that fulfil the complexity assessment module. These screens activate processes requiring inputs from the user and reports displaying outputs from the processes as follows:

**Processes**

A. **COMPLEXITY DIMENSION SIGNIFICANCE**
B. **UNCERTAINTY ASSESSMENT**
C. **COMPLEXITY DIMENSION SIGNIFICANCE ASSESSMENT**
D. **COMPLEXITY TYPE SIGNIFICANCE ASSESSMENT**
E. **COMPLEXITY SCORING**

**Reports**

F. **WBS COMPLEXITY MATRIX**
G. **COMPLEXITY CORRELATION MATRIX**
H. **COMPLEXITY CHARTS**

**7. A. Complexity Dimension Significance**

This screen allows an expert to identify and specify the complexity dimensions in their costing scenario. It presents a catalogue of eleven complexity dimensions to the user. However, only eight dimensions will be assessed at any one time. The first five dimensions are mandatory, and the last three dimensions are selected from the remaining six. Figure 2.1-5A-1 presents a sample screen for complexity dimension specification. There are three fields on this screen:

- **Complexity Dimension** and for each dimension, the following fields apply:
- **Significance for Costing** which is a tick for selecting the non-mandatory dimensions
- **Assess Uncertainty** which is a tick to select which dimensions should be evaluated for uncertainty

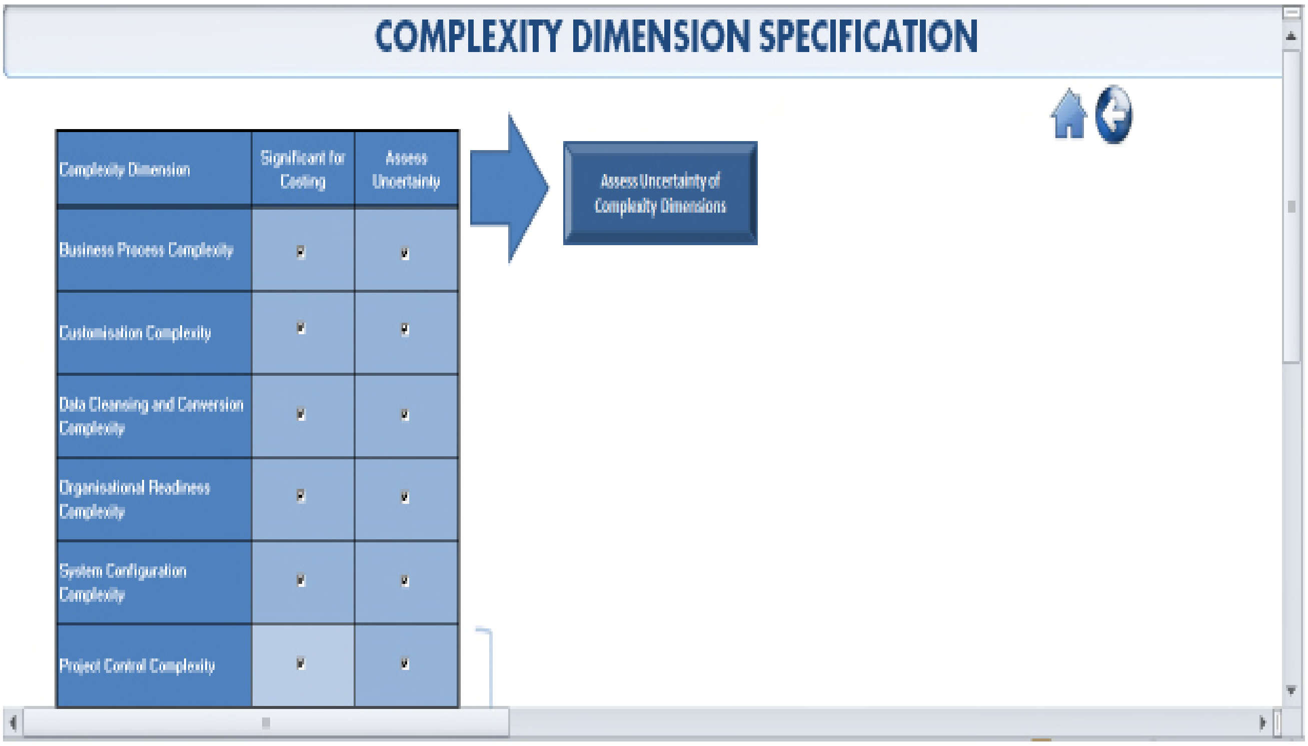



Figure 2.1-5A-1: Complexity Dimension Specification

**7B. Uncertainty Assessment**

The process of ERP system assessment involves numerous problems because the business environment is influenced by high uncertainty. This difficulty necessitates uncertainty evaluation for ERP complexities and challenges. C-REACT accomplishes this aim by assessing the uncertainty of the estimates for the identified ERP complexities through the use of a NUSAP pedigree matrix technique depicted in Figure 2.1-7B-1. This provides the user with a degree of confidence in relation to the data provided for the complexities. The uncertainty evaluation is fulfilled at the beginning of the complexity assessment process, following the complexity identification where complexity dimensions are specified. The assessment process will be conducted with the aid of an ERP implementation expert.

.

The complexities for which their uncertainty will be assessed are presented at the dimension level. Therefore, the eight complexity dimensions identified in (7A) will be presented to the user for uncertainty assessment. Two options will be displayed for selection of a suitable assessment method: (1) NUSAP pedigree matrix; and (2) a manual scoring method.

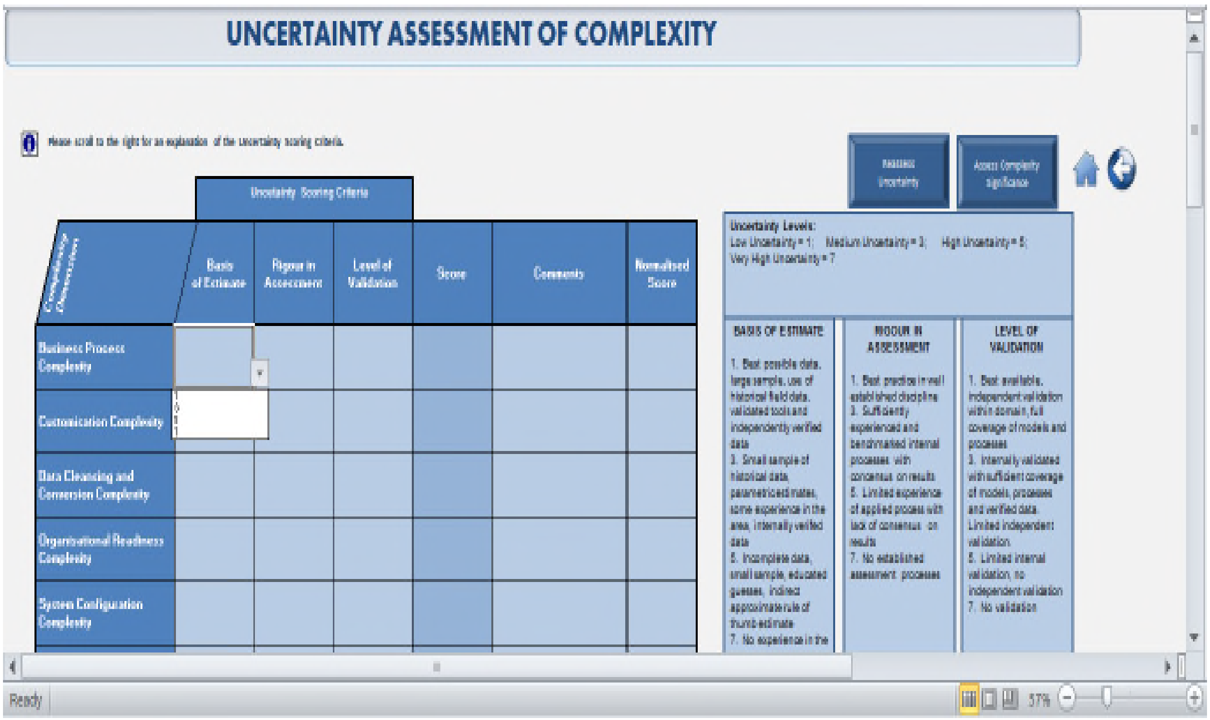


Figure 2.1-7B-1: Uncertainty Evaluation of Complexity using the NUSAP Pedigree Matrix

The uncertainty for the estimates provided for each complexity dimension is evaluated on the screen depicted in Figure 2.1-7B-1. The fields on this screen are:

- **Complexity Dimension**
- **Basis of Estimate** is one of the criteria upon which the complexity dimension is measured. It is on a ranking scale of 1, 3, 5 and 7.
- **Rigour in assessment** is the second criteria upon which the complexity dimension is measured, and is also on a ranking scale of 1, 3, 5 and 7.
- **Level of Validation** is the third criteria which was defined for measuring the selected complexity dimension. Its ranking scale is from 1 to 7 (1, 3, 5 and 7).
- **Score** is the average of the ranks assigned across the three criteria above
- **Comments**

The pedigree criteria employed in C-REACT is illustrated in Figure 7B-1. The criteria are basis of estimate, rigor in assessment and level of validation. The criteria are described as:

- Basis of estimate: typically refers to the degree to which direct observations are used to estimate the variable. The focus of this measure is the level of data that is available to be able to make a cost estimate.
- Rigour in assessment: refers specifically to the methods used to collect, improve, and analyse the data that is used to apply cost estimation.

- Level of validation: this metric refers to the degree to which efforts have been made to cross-check the data against independent sources.

**Uncertainty Pedigree Matrix**

| | Uncertainty Level | Basis of Estimate | Rigour in Assessment | Level of Validation |
|---|---|---|---|---|
| Low | 1 | Best possible data, large sample, use of historical project data, direct measurements and independently verified data | Best practice in well-established discipline | Best available independent validation within domain, full coverage of models, methodologies and processes |
| | 3 | Minimal sample of historical data, parametric estimates and modelled data, some experience in the area, internally verified data | Adequate experience of applied processes and methodologies, benchmarked internal processes and data, with consensus on reliability of results | Internally validated with sufficient coverage of models, processes, methodologies and verified data. Limited independent validation. |
| | 5 | Incomplete data, small sample, educated guesses, indirect approximate rule of thumb estimate | Limited experience of applied process and methodology, with lack of consensus on reliability of results | Limited internal validation, no independent validation. |
| High | 7 | Crude speculation | No established assessment processes | No validation |

Figure 2.1-7B-1: NUSAP Pedigree Matrix for Uncertainty Assessment of Complexity Estimates

It is illustrated in Figure 2.1-7B-1 that uncertainty increases with the ranking. Each complexity dimension is ranked according to the pedigree criteria. For each dimension, an average score is obtained across all three ranks. This is known as the uncertainty score.

The uncertainty score is used in the complexity costing process described in section 3.2. The score varies the complexity cost. A low uncertainty increases the confidence level of the potential ERP adopting organisation. This means that to attain a low uncertainty, the validation process of the complexity estimate must be thorough with sufficient information. This stage would usually fall into the implementation phase or just before implementation. At this stage, the organisation would have a well-defined project scope with clearly defined business requirements.

**7C. Complexity Dimension Significance Assessment**

This screen is used to assess the significance of each complexity dimension in relation to costing. Therefore, every complexity dimension is compared against another to derive a weight. When the expert has assessed the complexity dimensions, they may continue the assessment process as prompted by the tool. This presents them with the same process for all the complexity types associated with each dimension

The Complexity Dimension and Type Significance Assessment process involves the production of a weight for each complexity dimension and each complexity type. This is achieved by applying the **Analytical Hierarchy Process (AHP)** technique. One of the main strengths of AHP is its ability to cater for subjective opinions of decision makers. There are four steps in the multi-attribute evaluation of AHP as depicted in Figure 2.1-7C-1.

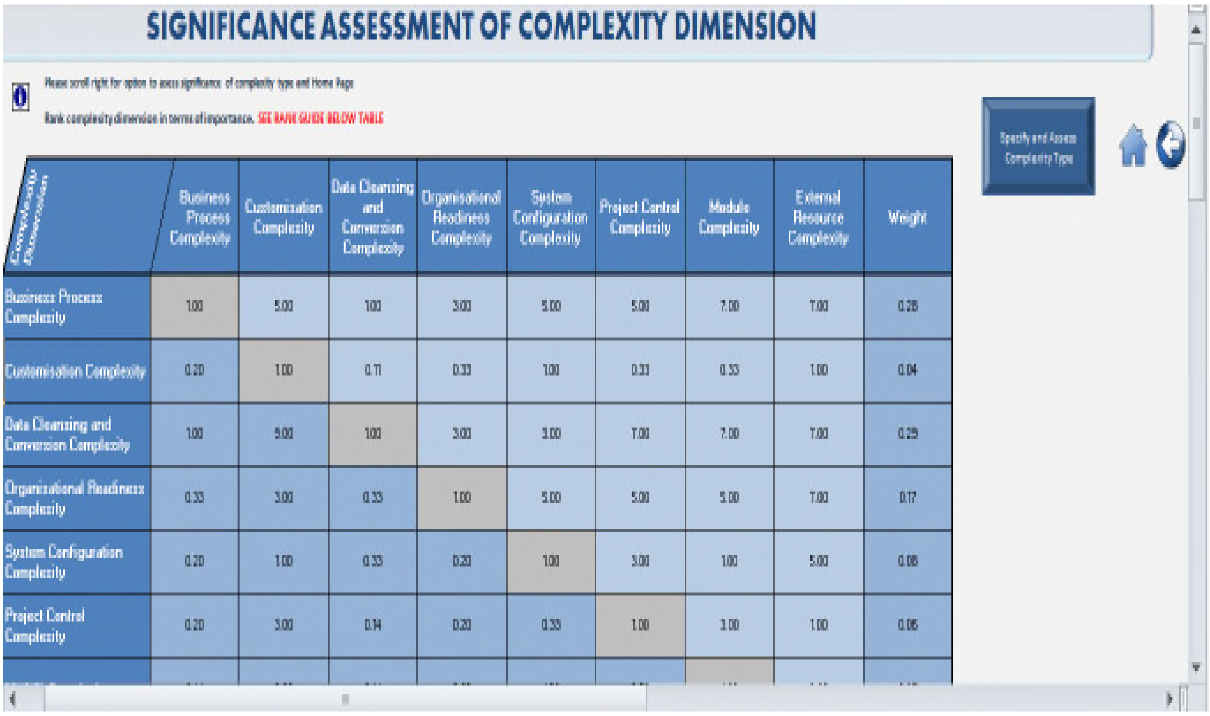

Figure 2.1-7C-1: Phases for Application of AHP

The *Decomposition Phase* entails the project team developing the AHP hierarchy. The hierarchy will be composed of a goal at the top and criteria and alternatives of choice at the bottom. The maximum number of complexity dimensions for comparison against each other is eight, and the maximum number of complexity types to be compared against each other is three. In the second phase, each decision maker utilises paired comparisons for the complexity dimensions and complexity types to extract judgment matrices. These paired comparisons are ranked using a nine-point scale at each level. The nine-point scale is highlighted in Table 2.1-7C-1. The third phase involves the repetition of the paired comparison process for each complexity in the alternative prioritisation problem to compute local weights. The fourth step which is executed automatically by the tool, involves aggregating the weights to obtain the importance of attributes and the global priority of alternatives.

| Scale | Numerical Rating | Reciprocal |
|---|---|---|
| **Minimal Importance** | 1 | 1 |
| **Somewhat greater importance** | 3 | 0.33 |
| **Strong importance** | 5 | 0.20 |
| **Very strong importance** | 7 | 0.14 |
| **Absolute (highest possible) importance** | 9 | 0.11 |

Table 2.1-7C-1: AHP Scale of Relative Importance

Traditionally, odd numbers from the nine-point scale are used in order to ensure a reasonable distinction among the measurement points. Even numbers may be used as well, but only in the case of negotiations in order to reach a compromise. In C-REACT, even numbers are not used. The rationale behind this decision is to enable estimators reach a concrete agreement on the importance of the complexities. Allowing intermediate values may introduce complacency and frivolity. The priority of comparison is prevalent in the criteria in row headings over those in the column headings. Figure 2.1-7C-2 and Figure 2.1-7C-3 present screenshot examples from C-REACT of the complexity dimensions and types using the AHP technique. Criteria with the same alternatives will have a ranking of 1. For instance, if business process complexity is compared against business process complexity, the ranking will be 1. In the event that an alternative is more important (for instance, 5 time more important) than another alternative, the latter will have the inverse value (0.20) of the former. Examples of these comparisons are illustrated in Figure 2.1-7C-2 and Figure 2.1-7C-3.




| Complexity Dimension | Business Process Complexity | Customisation Complexity | Data Cleansing and Conversion Complexity | Organisational Readiness Complexity | System Configuration Complexity | Project Control Complexity | Module Complexity | External Resource Complexity | Weight |
|---|---|---|---|---|---|---|---|---|---|
| Business Process Complexity | 1.00 | 5.00 | 1.00 | 3.00 | 5.00 | 5.00 | 7.00 | 7.00 | 0.28 |
| Customisation Complexity | 0.20 | 1.00 | 0.71 | 0.33 | 1.00 | 0.33 | 0.33 | 1.00 | 0.04 |
| Data Cleansing and Conversion Complexity | 1.00 | 5.00 | 1.00 | 3.00 | 3.00 | 7.00 | 7.00 | 7.00 | 0.25 |
| Organisational Readiness Complexity | 0.33 | 3.00 | 0.33 | 1.00 | 5.00 | 5.00 | 5.00 | 7.00 | 0.17 |
| System Configuration Complexity | 0.20 | 1.00 | 0.33 | 0.20 | 1.00 | 3.00 | 1.00 | 5.00 | 0.08 |
| Project Control Complexity | 0.20 | 3.00 | 0.14 | 0.20 | 0.33 | 1.00 | 3.00 | 1.00 | 0.06 |

Figure 2.1-7C-2: Complexity Dimension Significance Assessment

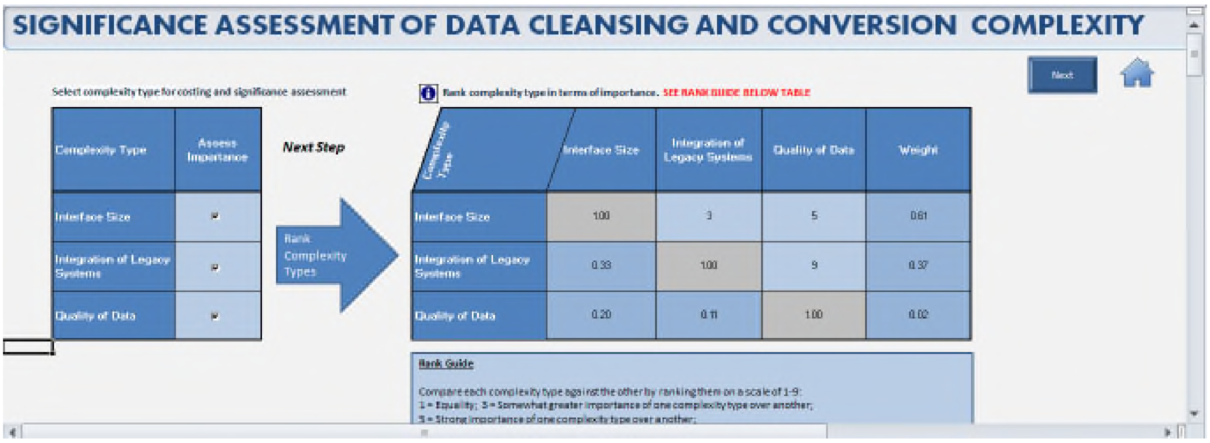



Figure 2.1-7C-3:  Complexity Type Significance Assessment

The user is enabled to input ranks against the alternatives on the right-handside of the cells with the value ‘1’ in the matrix.  The left-handside of the cells with the value ‘1’ is automatically calculated by the AHP algorithm in the tool, depending on the input of the user which is between 1 and 9.

The algorithm adopts the following logic:

- If the first alternative is equal to the second alternative, the value in the cell which they share is ‘1’ – this value is automatically determined by the tool; hence the user is not required to make any such entries
- If the second alternative is greater than zero, then the first alternative will be assigned the inverse value of the second alternative.
- If the second alternative is less than zero, then the first alternative will be assigned the value in the denominator of the first alternative.

The hierarchy for the complexity AHP matrix is based on two levels; the complexity dimension level and the complexity type level in relation to their importance in the context of costing.

The complexity dimensions are compared against each other and a weight is derived for each dimension.

**7D. Complexity Scoring**

The complexities are scored on this screen. Upon entry onto the screen, it presents the user with three options prompting the user the score the complexities based on a scenario. The complexity scores for each scenario are pre-defined. A fourth option is also offered to the user, which allows the user to specify their own complexity scores. The scenario screen is presented in Figure 2.1-7D-1 and the screen fields are highlighted in Figure 2.1-7D-2.

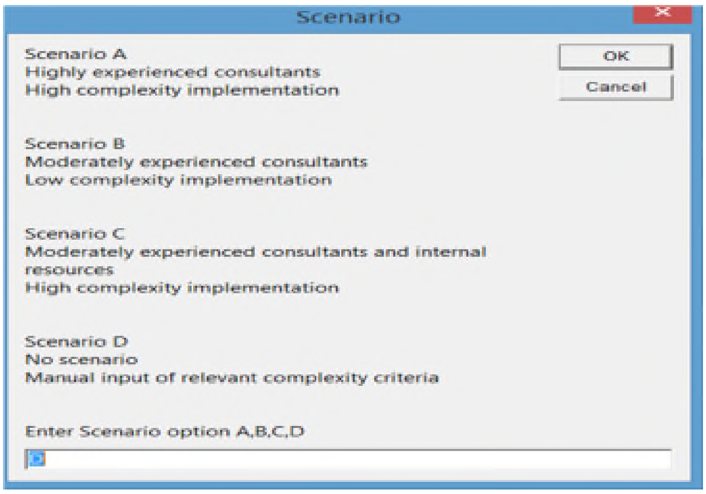



Figure 2.1-7D-1: Complexity Scenarios

The scenarios are as follows:

- Scenario A relates to highly experienced consultants in a high complexity implementation. C-REACT sets the complexity level for external resource experience to ‘1’ for very low complexity, and sets all other complexity levels to ‘5’ to denote a high complexity.
- Scenario B focuses on moderately experienced consultants in a low complexity implementation. Therefore C-REACT sets the complexity level for external resource experience to ‘3’ for medium

complexity, and sets all other complexity levels to ‘1’ for low complexity.

- Scenario C concerns moderately experienced consultants and internal resources in a high complexity implementation. Hence C-REACT sets the complexity levels for external resource experience and internal resource participation to ‘3’ for medium complexity, and sets all other complexity levels to ‘5’ for high complexity.
- Scenario D enables the user to specify their own complexity levels

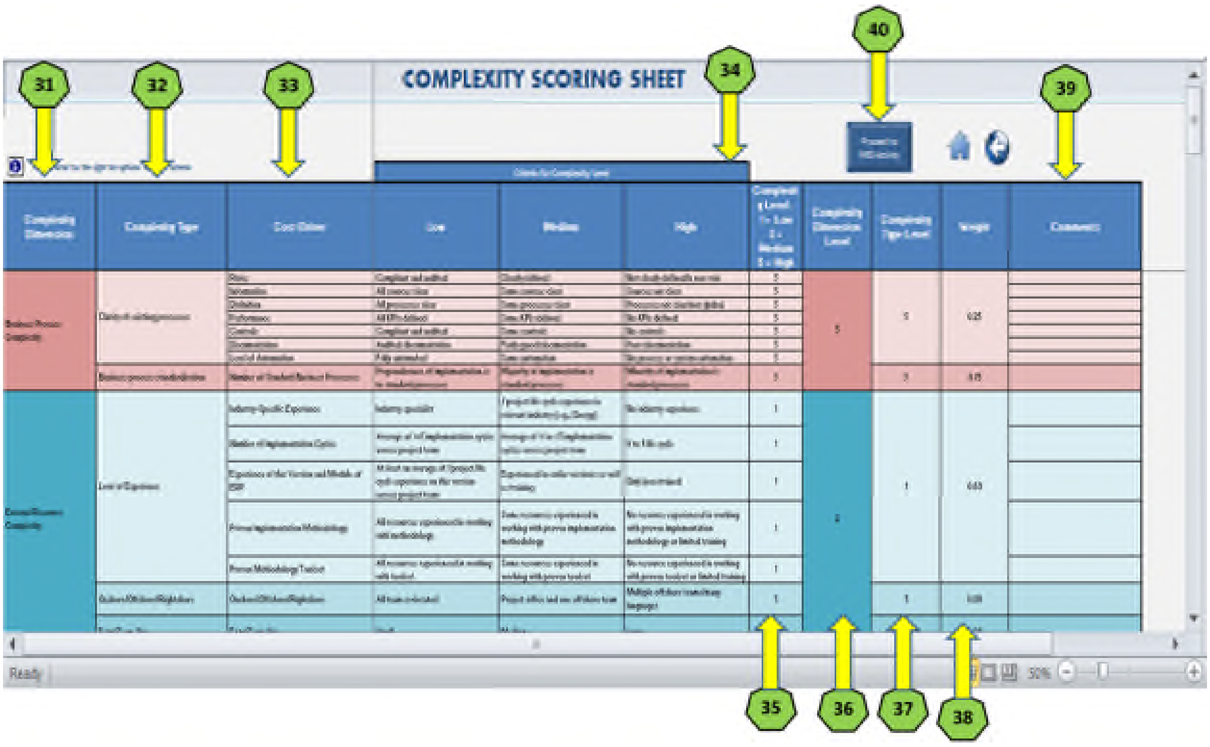



Figure 2.1-7D-2: Complexity Scoring Screen

The fields on the **Complexity Scoring** screen are:

- 31 - **Complexity Dimension**
- 32- **Complexity Type**
- 33 - **Cost Driver**
- 34 - **Criteria for Complexity Level** is defined for each cost driver:

   - ➢ Low applies to the complexity criteria for low complexity
   - ➢ Medium applies to the complexity criteria for medium complexity
   - ➢ High applies to the complexity criteria for a high complexity

- 35 - **Complexity Level** enables the user to specify a level based on any of the above-mentioned complexity criteria; the value '1' denotes a low complexity, '3' denotes a medium complexity and '5' denotes a high complexity.
- 36 - **Complexity Dimension Level** is an output field displaying the average score of all the complexity types for the relevant complexity dimension
- 37 - **Complexity Type Level** is an output field which displays the average of the scores of all its cost driver complexity levels input by the user. It is used in the cost estimating process. The highest number obtained is 5. Therefore, the final set of complexity levels range between 1 to 5. On the scale of 1 to 5; 1 means very low complexity, 2 is low complexity, 3 conveys medium complexity, 4 represents high complexity, and 5 means very high complexity.
- 38 - **Weight** is an output field which displays the weight for the relevant complexity type as derived from its earlier significance assessment
- 39 - **Comments**

## 7E. WBS Complexity Matrix

This is a report which classifies the complexity according to the activity they appear. This classification is fulfilled by indicating the normalised complexity score, Kessington's Complexity Number (KCN) in the relevant cell as illustrated in Figure 2.1-7E-1.

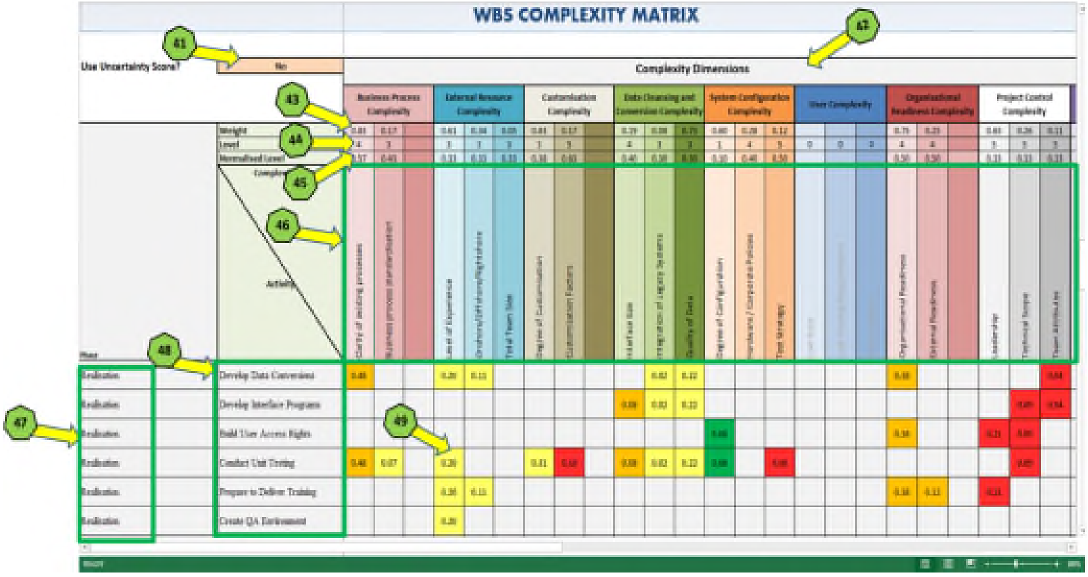



Figure 2.1-7E-1: WBS Complexity Matrix

This matrix is a form of reporting which informs the user of the complexities arising, and the areas in the project which require attention according to their level of complexity. This report enables the potential ERP adopting organisation to understand the complexities which they may face in the event that they implement ERP.

The fields on this screen are:

- 41 – **Use Uncertainty Score?** requires the user to specify whether they wish for this value to be incorporated in Kessington's Complexity Number.
- 42 – **Complexity Dimensions** lists the dimensions which have been selected by the user for assessment
- 46 – **Complexity Types** which fall under the relevant complexity dimensions, and which have been assessed, are listed across the matrix.
- 43 – **Weight** is an indication of the assessed complexity significance
- 44 – **Level** is an indication of the complexity type level which was calculated by the tool in the Complexity Scoring Sheet.

- **45** – **Normalised Level** is a number calculated for the complexity level of each complexity type on a scale of 0 to 1.
- **47** – **Phase** represents the project phase
- **48** – **Activity** represents the project activities which the complexity types appear in
- **49** – **Kessington's Complexity Number** (KCN) is a product of the complexity weight and normalised level. This number is used in the costing process, as will be discussed in section 2.2. These cells are indicated by colour. The colour changes between red through yellow and amber to green according to the complexity level. The lower end of the complexity level presents a green colour and changes to yellow as the level increases. The higher end of the complexity level displays a red colour in the relevant cell.

In addition to the above fields, there is a field known as Critical Path, as indicated in Figure 2.1-7E-2. This field is populated on this screen from the WBS.

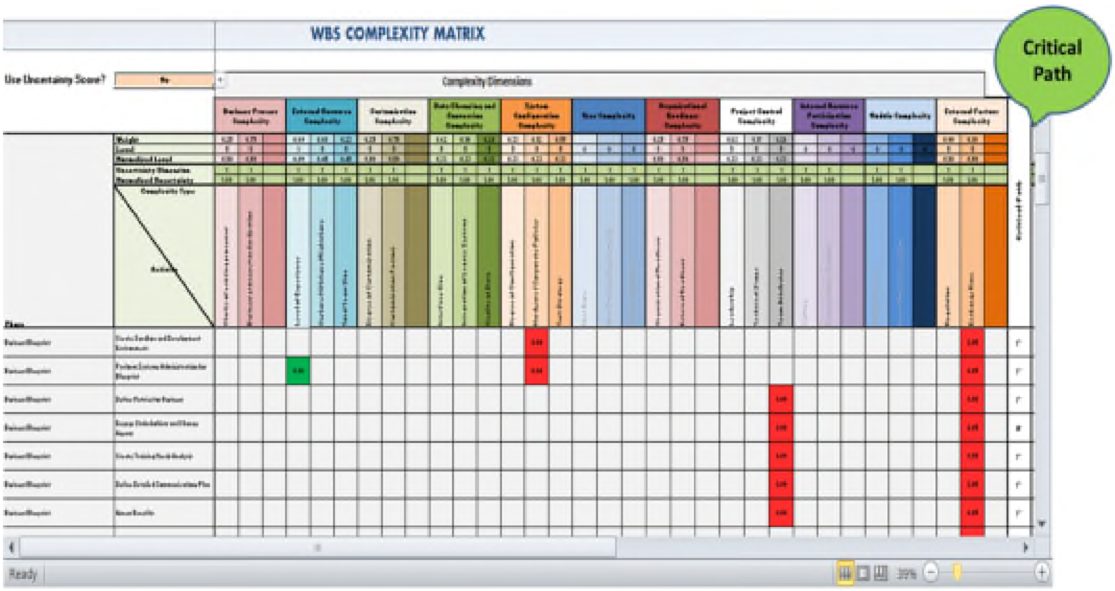



Figure 2.1-7E-2: WBS Complexity Matrix with Critical Path Field

The critical path field is ticked for any activity in a critical path, as specified in the WBS (Project Schedule).

## 7F. Complexity Correlation Matrix

This screen is a matrix which reports the potential complexities that may arise for each complexity type that exists in the complexity cost estimating scenario. The essence of the correlation report is to alert a potential ERP adopting organisation about the potential complexities which will emerge as a consequence of other complexities arising. This indicates to the organisation that the complexity cost is likely to rise beyond the estimated cost in the event that the initially reported complexities are not reduced. The complexity correlation matrix is presented in Figure 2.1-7F-1.

Each complexity is compared against every other complexity in the matrix by adopting the AHP technique, but without applying quantitative values. The correlation is reported in terms of positive and negative correlation. A positive correlation is a relationship between two complexities, where an increase in one causes an increase in the other. Additionally, a decrease in one complexity causing a decrease in the other reflects a positive correlation.

An example of a positive correlation between the complexity types, clarity of business process and customisation factors is that in the event that business processes are not clear, the definition of customisation items will most likely not be clear either. On the other hand, a negative correlation between two complexity types causes one of the complexity types to conduct the opposite of what the other one reflects. For instance, a correlation between clarity on business process and onshore/offshore/rightshore resources indicates that the less clarity there is on business processes will effect a higher proportion of required onshore resources.

Each correlation is explained in the note for each complexity type that has a correlation with another.

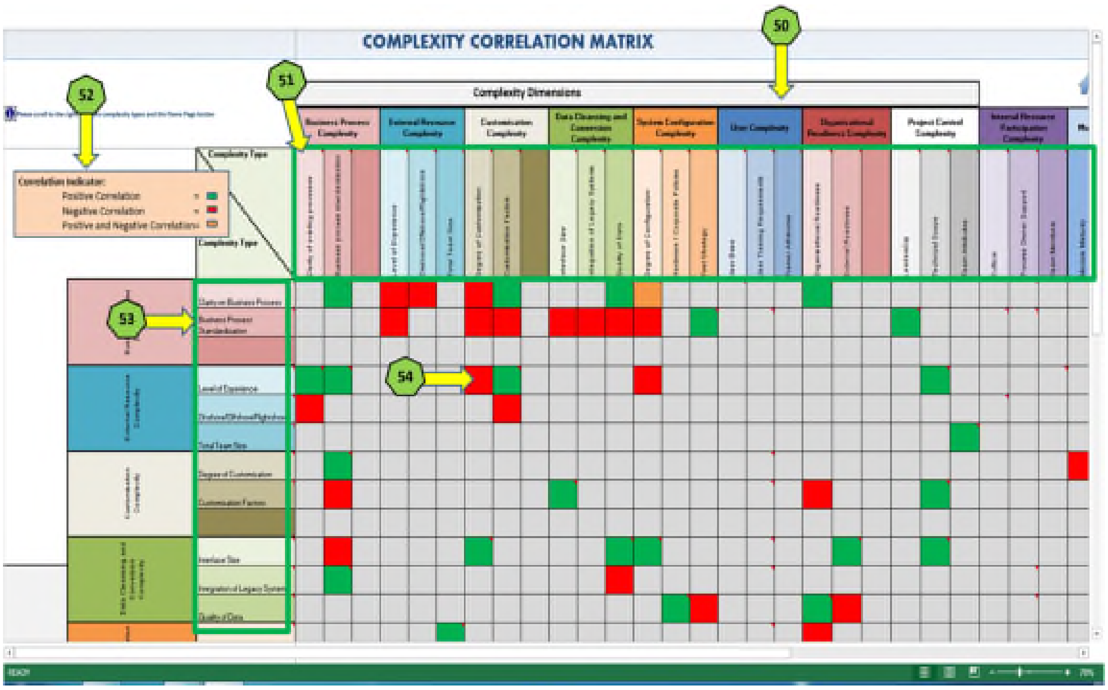



Figure 2.1-7F-1: Complexity Correlation Matrix

The fields on this screen are:

- **50** – **Complexity Dimensions** which have been selected by the user for assessment
- **51** – **Complexity Types** which will be correlated
- **53** - **Complexity Types** against which the above complexity types will be correlated
- **52** – **Correlation Indicator** provides a legend explaining the different types of correlation
    - Positive correlation is indicated with a green colour in the relevant cell

- ➢ Negative correlation is indicated with a red colour in the relevant cell
- ➢ Positive and negative correlation is indicated with amber in the relevant cell

- **54** - Correlation

**7G. Complexity Charts**

The complexity charts provide a radar chart indicating the levels of the various complexities by dimension, and a bar chart indicating the complexity level for each complexity type. The radar chart is presented in Figure 2.1-7G-1 and the bar chart is presented in Figure 2.1-7G-2.

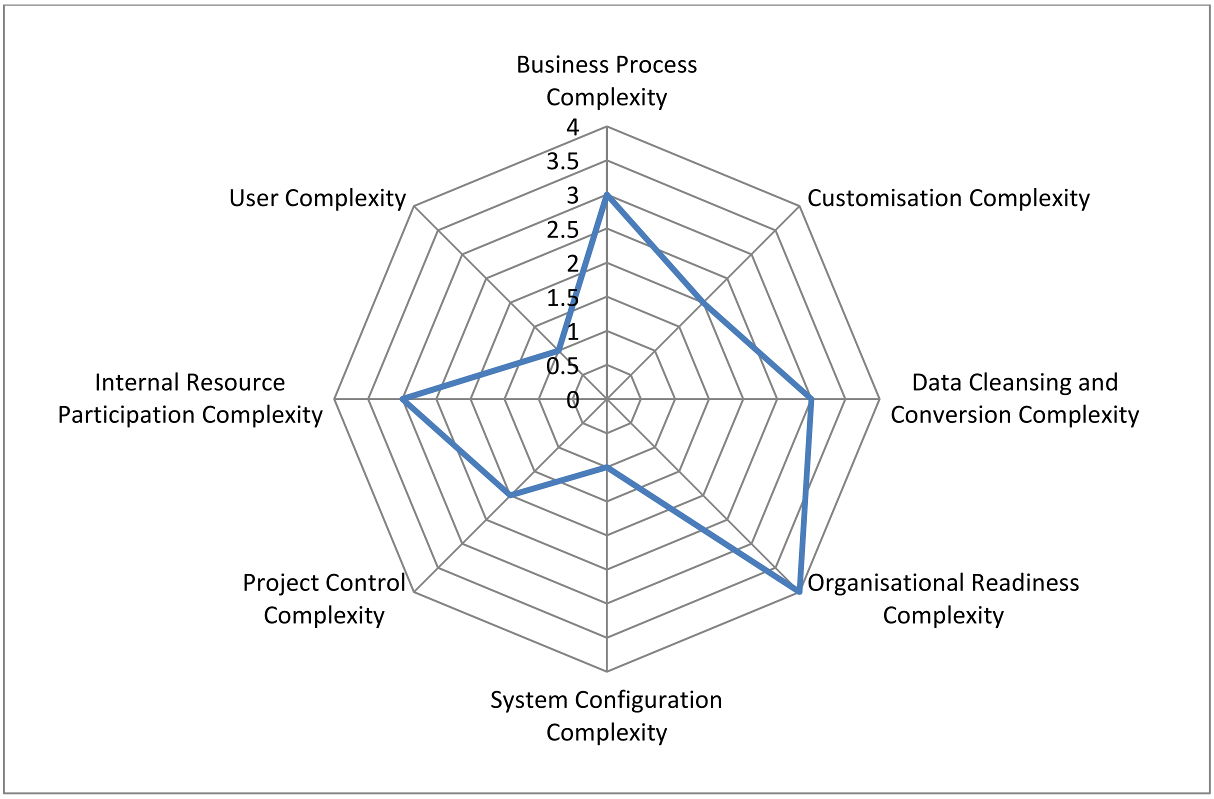



Figure 2.1-7G-1: Bar Chart of Complexity Levels by Complexity Dimension

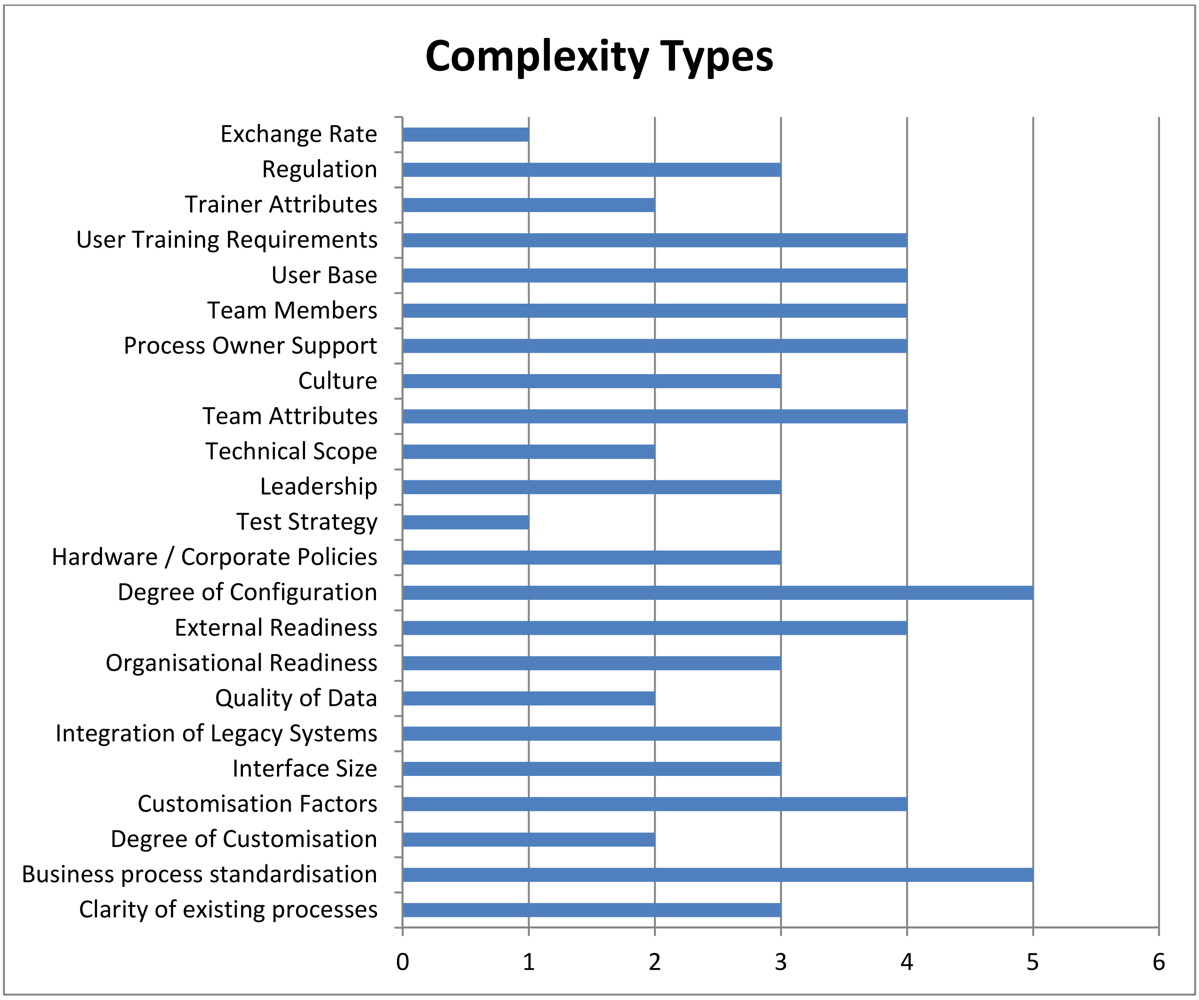



Figure 2.1-7G-2: Bar Chart of Complexity Levels by Complexity Type

## 8. Create Input File for Module 3

At the end of the complexity assessment process, when the user is ready to run Module 3 for resource complexity cost estimation, they should return to the main menu as presented in Figure 2.1-8-1.

On the main menu, the user should click the **ANYLOGIC** button. Immediately after this action, a different file is presented which is known as "**Copy of ERP Complexity Costing Tool for AnyLogic**". When the user saves this file, they should suffix the filename with "**_01**". This file contains the relevant data which is required for the resource complexity cost estimation.

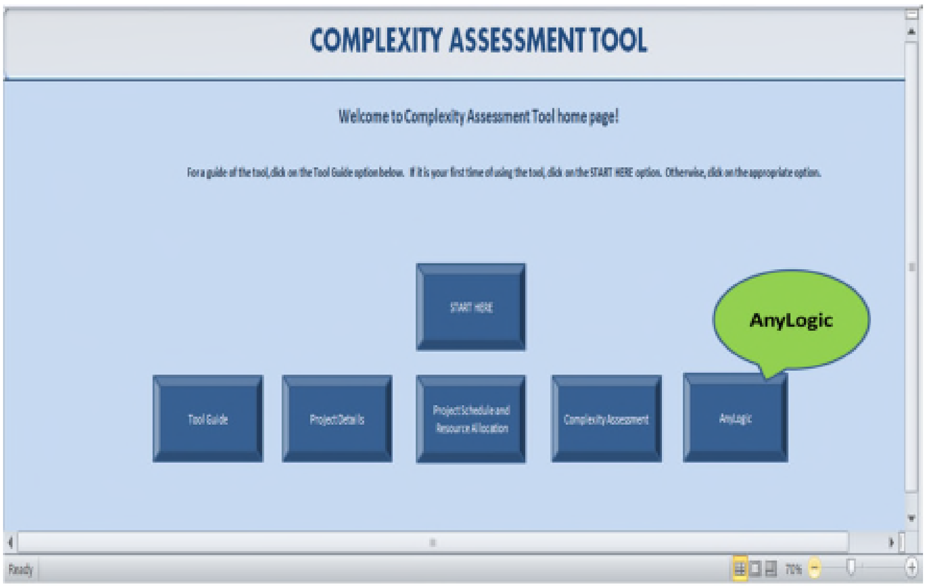



Figure 2.1-8-1: Welcome Page of C-REACT Complexity Assessment

## 2.2 C-REACT Cost Estimation of Dynamic Resource Complexity

This phase of the C-REACT tool executes Module 3 which simulates the costing of resource complexities which have been assessed in the Complexity Assessment process. Agent-based modelling (ABM) is used for this purpose as agent systems represent a new way of analysing, designing and implementing complex software systems. Agent-based modelling enables the ability to address individual complex behaviours and emergent patterns. Agents may be modelled as organisations, individuals or projects. In C-REACT, the resources in the WBS are represented as individual agents in ABM. The project activities which are specified in the work breakdown structure (WBS) of C-REACT are properly modelled using this technique. Furthermore, ABM may be used in circumstances where the level of complexity is not known beforehand. And due to its capability of emergence, it may lead to nonlinear individual agent behaviours. These characteristics offered by ABM are well suited to C-REACT because its complexity assessment process is dynamic. The final complexity score which is the Kessington's complexity number (KCN) is not known for each type of complexity until the completion of the assessment. Therefore the complexity cost for each resource cannot be estimated until KCN is presented. However, one of the disadvantages of an agent-based model is that it can only serve a specific purpose because a general purpose model will not suffice.

The simulation of ERP complexity cost estimation will enable organisations to visualise the growth or reduction of complexity and its impact on cost as it occurs. This will allow dynamic decision-making by potential ERP adopters in their contemplation to implement ERP and in their attempt to budget for future ERP implementations. The dynamism of ABM also encourages scenario analysis, thereby allowing a potential ERP adopter to run several scenarios through the model. This produces a richer and more robust basis for decision-making.

Upon completion of Module 1 and Module 2, the user should click the **Exit** button and return to the initial home page. Three buttons are presented to the user, as illustrated in Figure 2.2-1. Also, several buttons will appear on the tool bar. The user should click the button at the top of the screen labelled **55**. This button runs the model. So long as the model is paused or not yet running, this button will be presented on the relevant screen. The second button at the bottom of the screen labelled **SIMULATION OF RESOURCE COMPLEXITY COSTS** could also be selected to run Module 3. The user will be presented with another screen labelled **RESOURCE COMPLEXITY COST ESTIMATION** as presented in Figure 2.2-2.

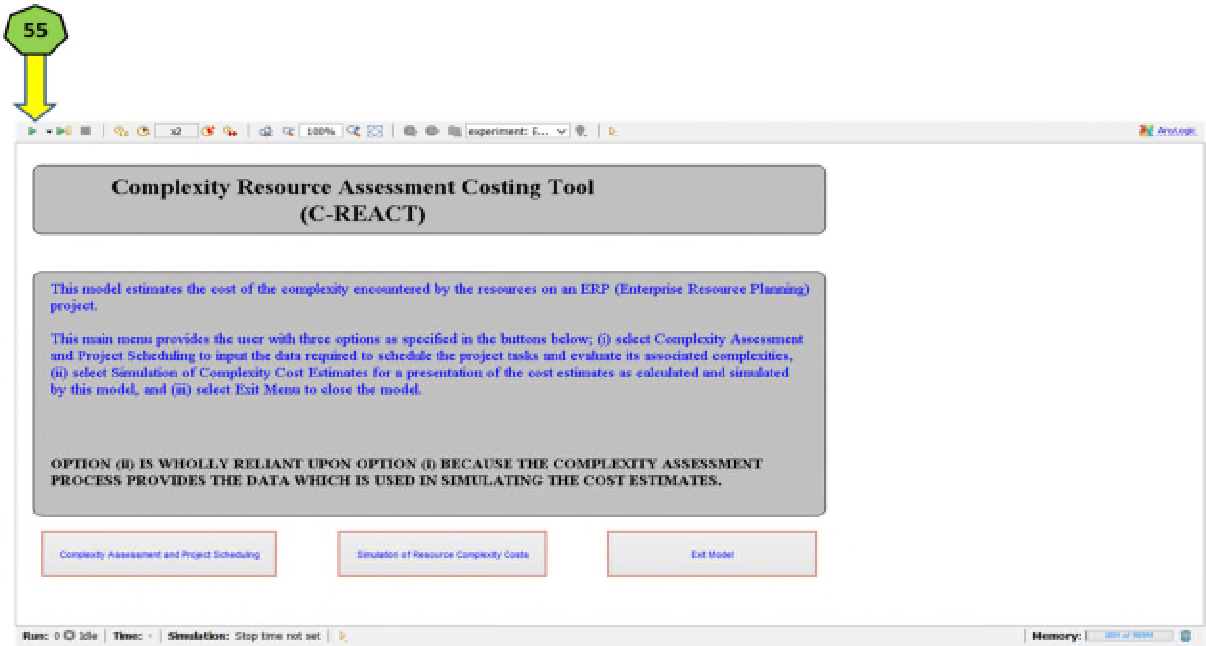



Figure 2.2-1: Home Page of C-REACT

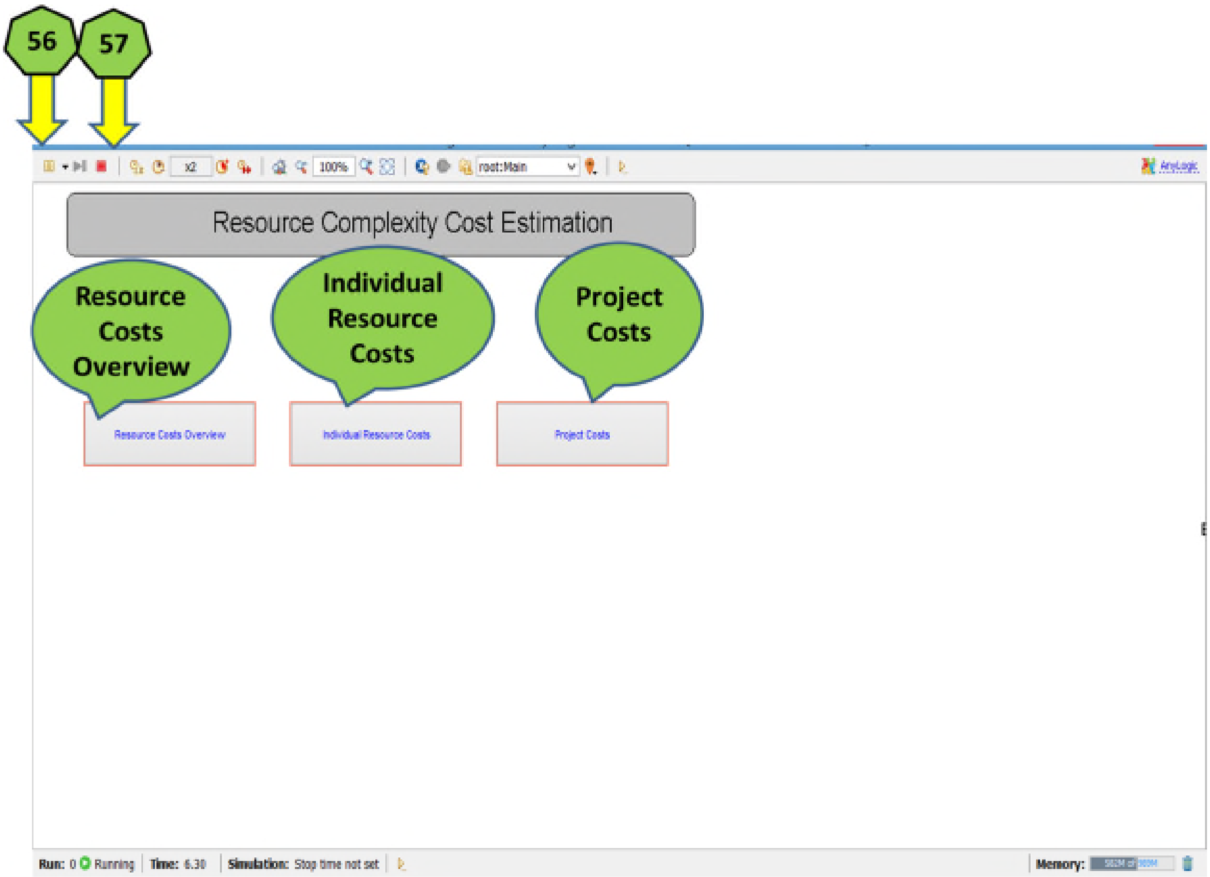



Figure 2.2-2: Screen for Resource Complexity Cost Estimation

This screen presents three buttons, each leading to a different screen with the same label as the button:

1. **RESOURCE COSTS OVERVIEW**
2. **INDIVIDUAL RESOURCE COSTS**
3. **PROJECT COSTS**

The button labelled **56** at the top of the screen will appear on all screens so long as the model is running. When clicked, it pauses the model. The button labelled **57** is used to stop the model from running completely.

### 1. Resource Costs Overview

This screen presents the user with three charts, each one for all the resources:

- **Resource Base Costs** (see Figure 2.2-1-3)
- **Resource Complexity Costs** (see Figure 2.2-1-4)
- **Resource Total Costs** (see Figure 2.2-1-5)

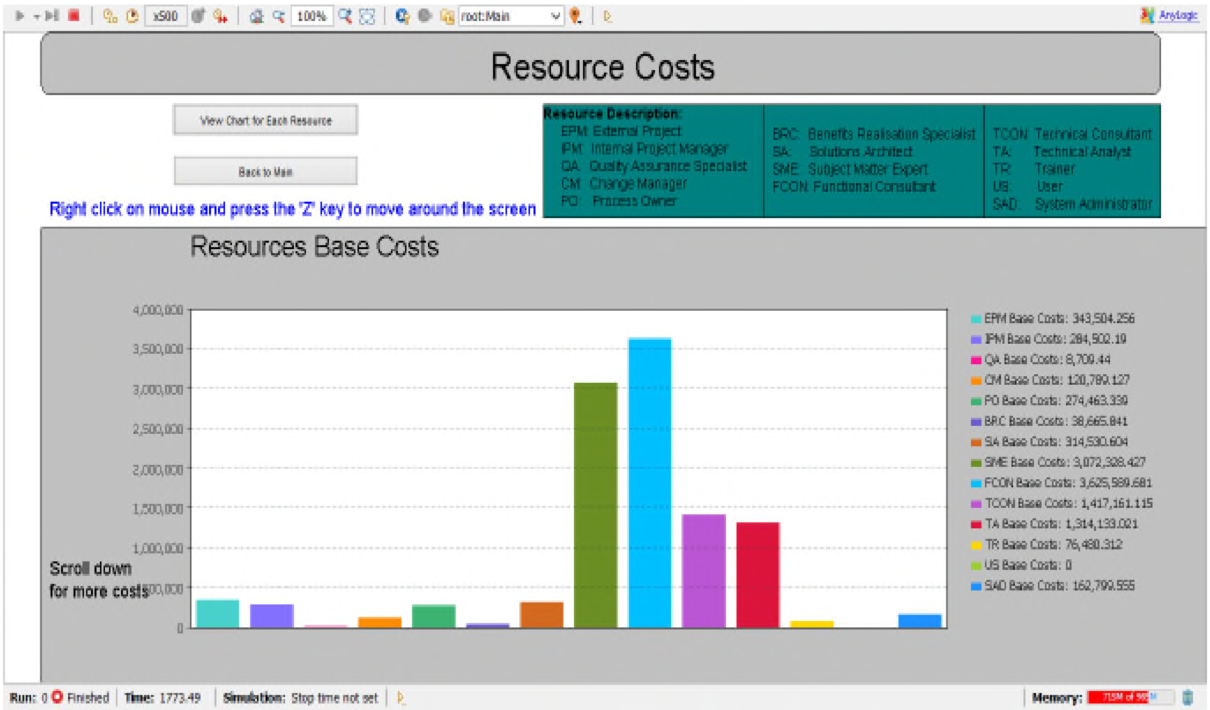


Figure 2.2-1-3: Resource Base Costs

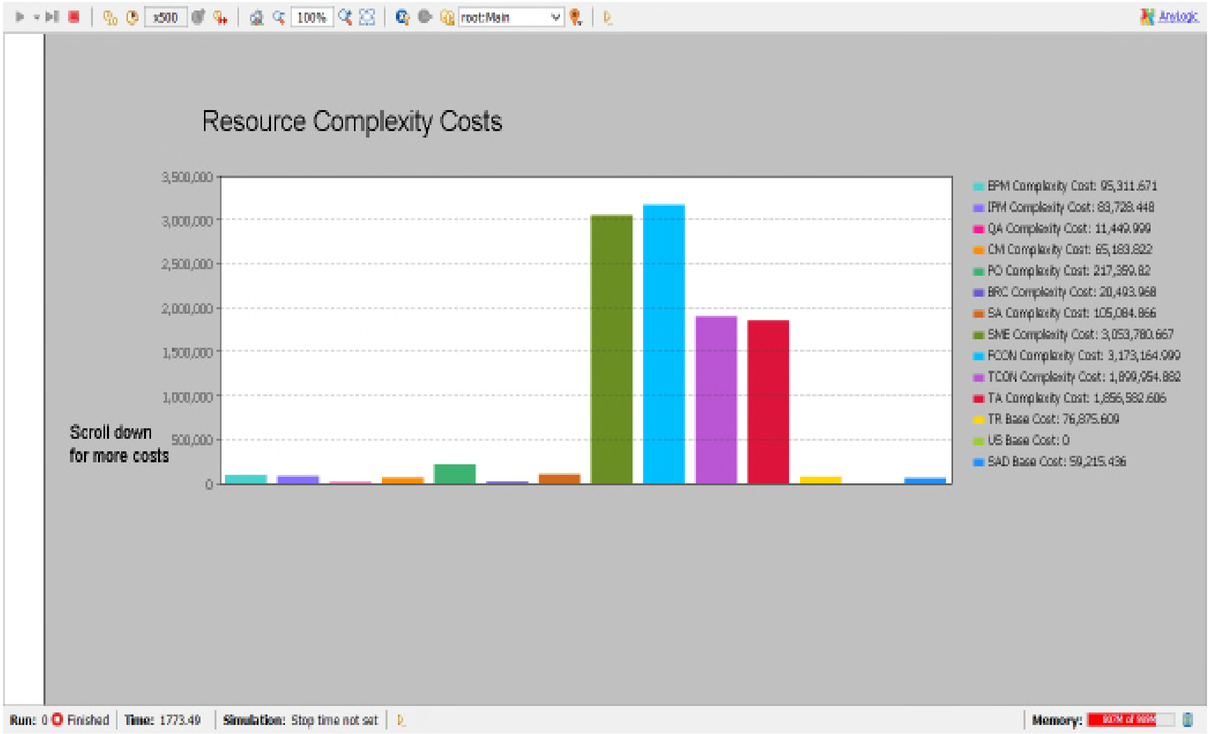



Figure 2.2-1-4: Resource Complexity Costs

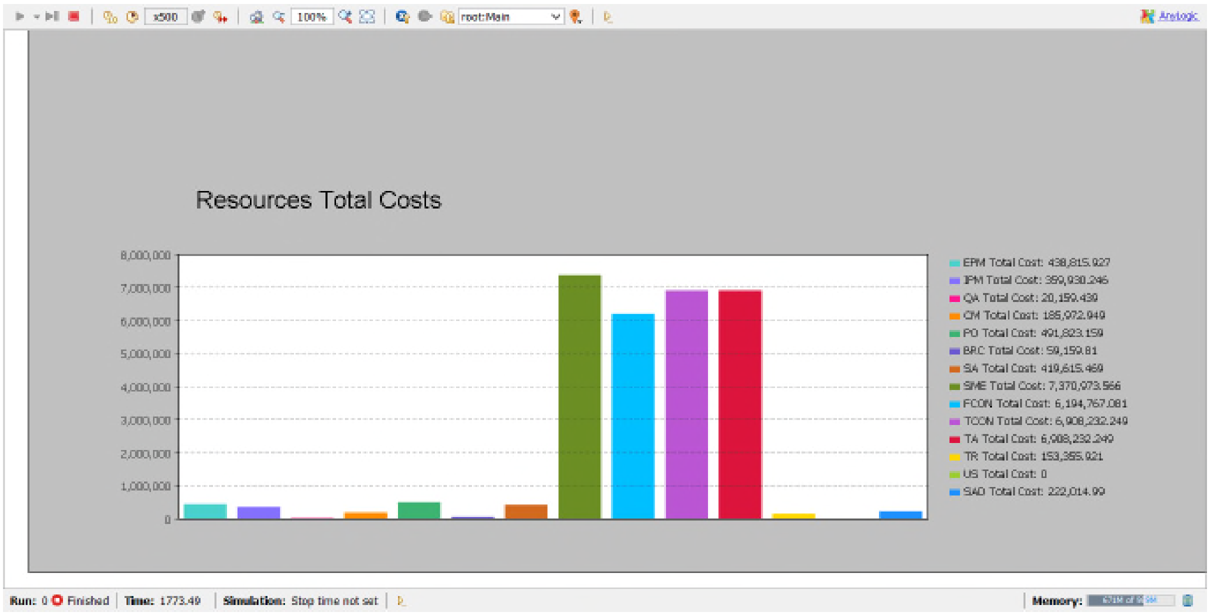


Figure 2.2-1-5: Resource Total Costs

The button **VIEW CHART FOR RESOURCES** at the top of the screen in Figure 2.2-3 returns the user to the **RESOURCE COMPLEXITY COST ESTIMATION** screen. The second button at the top of the screen is labelled **BACK TO MAIN**, and it takes the user back to the home page.

## 2. Individual Resource Costs

This screen presents images of all the resource types representing the team members on the ERP project, as depicted in Figure 2.2-2-1. The description for each team member is provided at the top of Figure 2.2-1-3. Clicking on any of the resources leads to a separate screen which illustrates the charts for each resource. The buttons on this screen are the same for all resources. The example that will be demonstrated in this section is for the External Project Manager (see Figure 2.2-1-4).

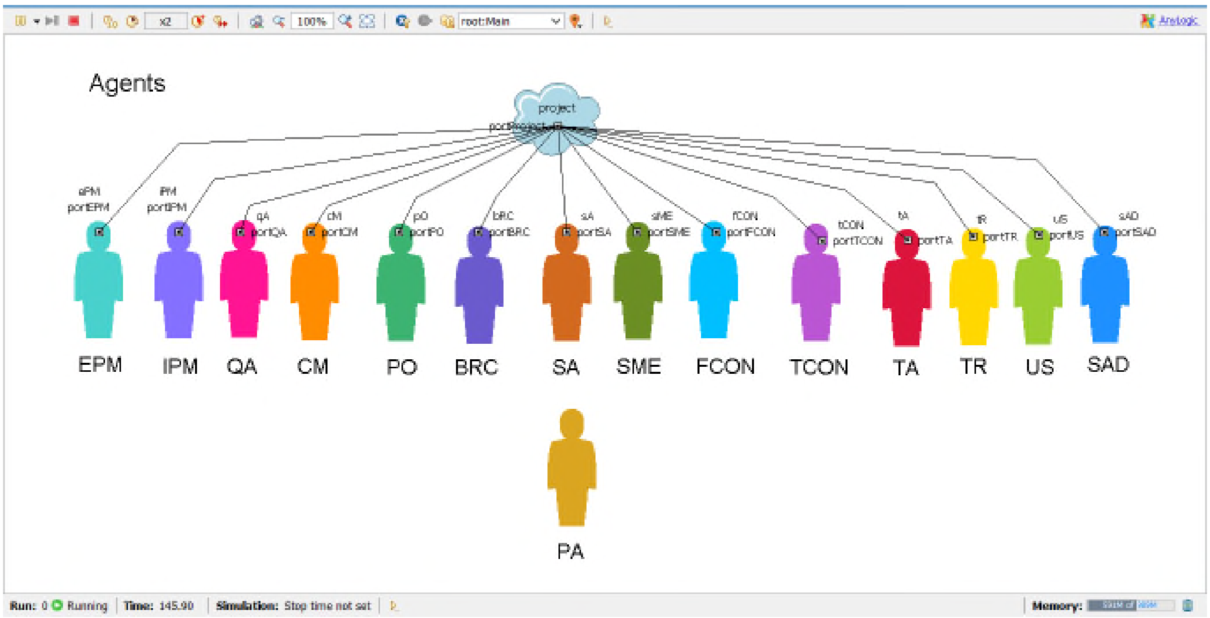



Figure 2.2-2-1: Project Team Members

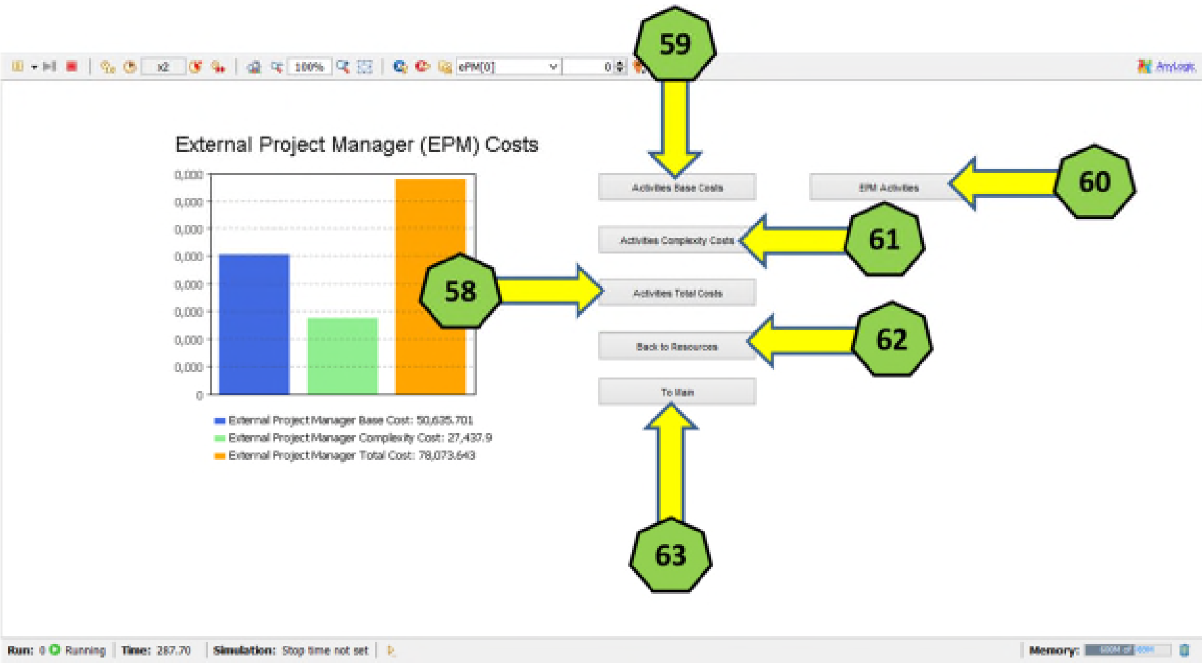



Figure 2.2-1-4: External Project Manager Costs

This screen presents a chart illustrating the base costs, resource costs and total costs for the external project manager. The following buttons are also displayed:

- **59** – **ACTIVITIES BASE COSTS** which presents a screen with the base costs for the project activities
- **60** – **EPM ACTIVITIES** which leads the user to a screen depicting the simulation of the external project manager activities, indicating each activity as the manager works on it and moves onto the next activity. Figure 2.2-1-5 illustrates a subset of the project activities for the external project manager, with a statechart.
- **61** – **ACTIVITIES COMPLEXITY COSTS** presents a screen with the complexity costs for the project activities
- **58** – **ACTIVITIES TOTAL COSTS** is a screen which displays the total costs for the project activities

- **62** – **BACK TO RESOURCES** returns the user to the **PROJECT TEAM MEMBERS** screen
- **63** – **TO MAIN** returns the user to the main menu

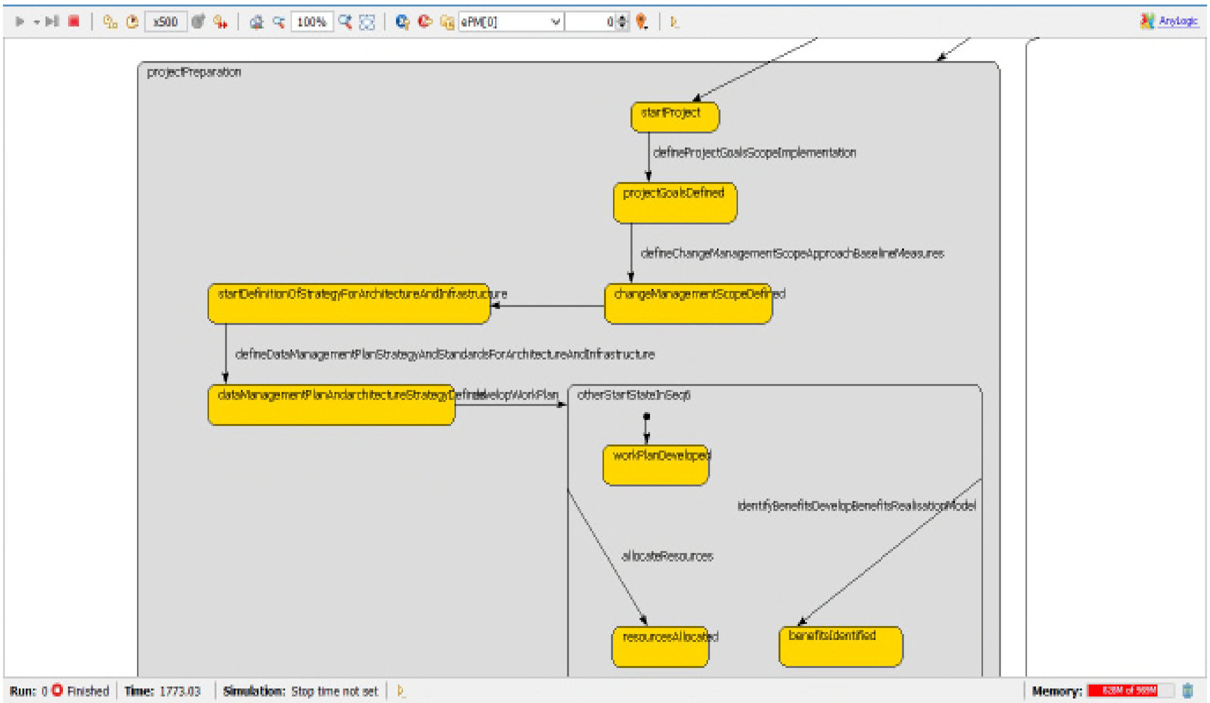
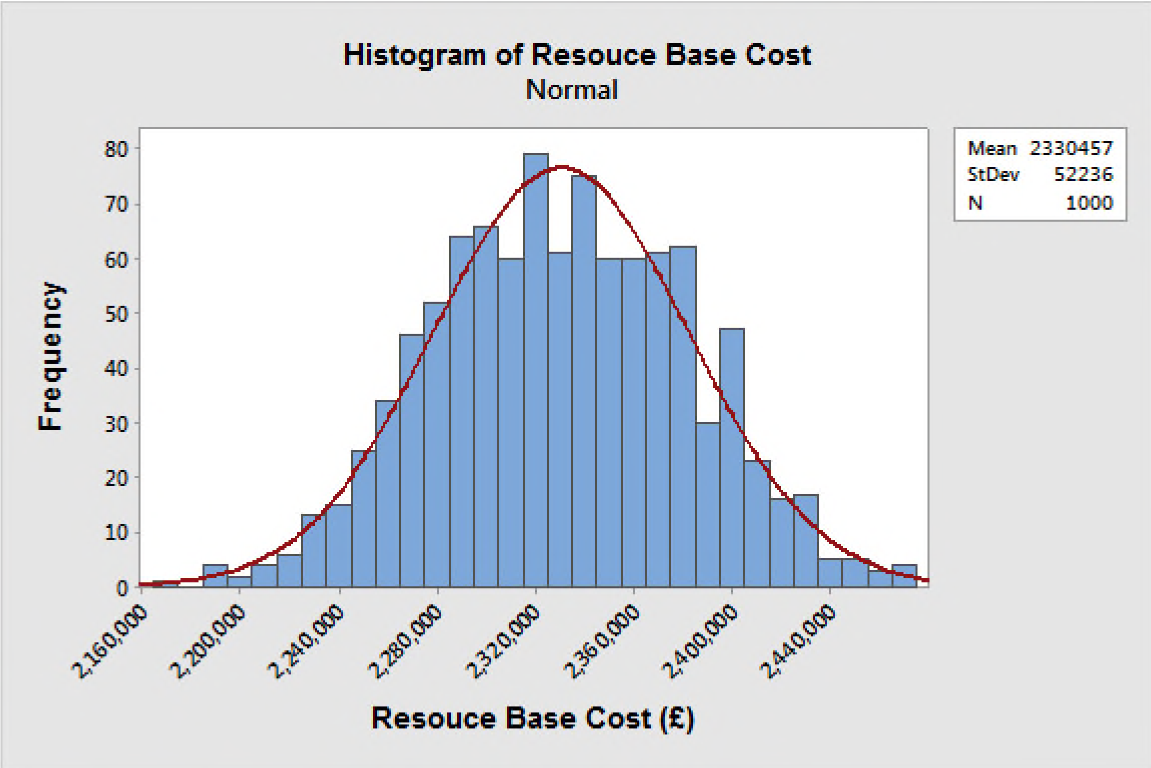



Figure 2.2-1-5: External Project Manager Statechart

### 3. Monte Carlo Simulation

The outputs which are obtained as resource complexity cost estimates are run through a Monte Carlo simulation one thousand times in order to account for uncertainty. A distribution is not pre-specified in this process. The distributions with the best fit will be applied to the ERP implementation budget by the potential adopting organisation.




This concludes the user instructions for the complexity of resource and assessment costing tool.

# Appendix E : Code for Complexity Calculation

This section outlines the code developed in AnyLogic for complexity calculation of the internal project manager. This code is embedded in the complexity of resource and assessment costing tool (C-REACT). This code is applied to all other agents in C-REACT.

### Function for Calculating Complexity Cost for IPM

```
String sheet = "WBS Activity Complexity (AL)";
int rowActivity=rowActivityComplexityMatrix;
double baseCost=baseCostActivity;
double complexityCostValue=0;
double aggregatedComplexityCostValue=0;
double complexityCostActivityMin=0;
double complexityCostActivityMax=0;
double complexityCostActivityMod=0;
double complexityCostActivity=0;
int column;
double normalisedUncertainty=0;
double uncertaintyPercentage=0;
double uncertaintyCost;
double rangeMinPercentage;
double rangeMaxPercentage;


if     (excelFile1.getCellStringValue("WBS     Activity     Complexity
(AL)!C5")=="Yes"){
      if   (excelFile1.getCellBooleanValue("WBS   Activity   Complexity
(AL)",rowActivity,37)==true){ //Activity in Critical path. Uncertainty
cost must be calculated
            for (column=4;column<=36;column++){
            // 33 cells are visited to evaluate whether they had a
zero value or not. The following block of code will be executed 33
times
```

```
if
(excelFile1.getCellNumericValue(sheet,rowActivity,column)==0.0) {}

else{
double
complexityPercentageValue=excelFile1.getCellNumericValue(sheet,rowActi
vity,column);

complexityCostValue=baseCost*complexityPercentageValue;

normalisedUncertainty=excelFile1.getCellNumericValue(sheet,12,co
lumn);
// Uncertainty cost calculation
if
(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP
Uncertainty
Percentages!B8")&&normalisedUncertainty<=excelFile1.getCellNumericValu
e("NUSAP Uncertainty Percentages!C8")){

uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP
Uncertainty Percentages!I8");
}
else
if(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP
Uncertainty
Percentages!B9")&&normalisedUncertainty<=excelFile1.getCellNumericValu
e("NUSAP Uncertainty Percentages!C9")){

uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP
Uncertainty Percentages!I9");
}
else
if(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP
Uncertainty
Percentages!B10")&&normalisedUncertainty<=excelFile1.getCellNumericVal
ue("NUSAP Uncertainty Percentages!C10")){

uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP
Uncertainty Percentages!I10");
}
else
if(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP
Uncertainty
Percentages!B11")&&normalisedUncertainty<=excelFile1.getCellNumericVal
ue("NUSAP Uncertainty Percentages!C11")){
```

```
uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP Uncertainty Percentages!I11");

                        }

                        else
if(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP Uncertainty Percentages!B12")&&normalisedUncertainty<=excelFile1.getCellNumericValue("NUSAP Uncertainty Percentages!C12")){

      uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP Uncertainty Percentages!I12");

                        }

      uncertaintyCost=complexityCostValue*uncertaintyPercentage/100;

      complexityCostValue=complexityCostValue+uncertaintyCost;    //New Complexity cost for complexity dimension with value different from zero

      aggregatedComplexityCostValue=aggregatedComplexityCostValue+complexityCostValue; // The sum of complexity costs for each complexity dimension with value different from zero

                  }

            }

      complexityCostActivityMod=aggregatedComplexityCostValue;

      }

      else if (excelFile1.getCellBooleanValue("WBS Activity Complexity (AL)",rowActivity,37)==false){

            for (column=4;column<=36;column++){

                  if
(excelFile1.getCellNumericValue(sheet,rowActivity,column)==0.0) {}

                  else{

                        double
complexityPercentageValue=excelFile1.getCellNumericValue(sheet,rowActivity,column);

      complexityCostValue=baseCost*complexityPercentageValue;
```

```
      aggregatedComplexityCostValue=aggregatedComplexityCostValue+comp
lexityCostValue;

                  }

            }

      }

      complexityCostActivityMod=aggregatedComplexityCostValue;

}


else    if(excelFile1.getCellStringValue("WBS    Activity    Complexity
(AL)!C5")=="No"){

      if   (excelFile1.getCellBooleanValue("WBS   Activity   Complexity
(AL)",rowActivity,37)==true){ //Activity in Critical path. Uncertainty
cost must be calculated

            for (column=4;column<=36;column++){

            // 33 cells are visited to evaluate whether they had a
zero value or not. The following block of code will be executed 33
times

                  if
(excelFile1.getCellNumericValue(sheet,rowActivity,column)==0.0) {}


                  else{

                        double
complexityPercentageValue=excelFile1.getCellNumericValue(sheet,rowActi
vity,column);


      complexityCostValue=baseCost*complexityPercentageValue;


      normalisedUncertainty=excelFile1.getCellNumericValue(sheet,12,co
lumn);

                        // Uncertainty cost calculation

                        if
(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP
Uncertainty
Percentages!B8")&&normalisedUncertainty<=excelFile1.getCellNumericValu
e("NUSAP Uncertainty Percentages!C8")){


      uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP
Uncertainty Percentages!I8");

                        }
```

```
                        else
if(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP
Uncertainty
Percentages!B9")&&normalisedUncertainty<=excelFile1.getCellNumericValu
e("NUSAP Uncertainty Percentages!C9")){

      uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP
Uncertainty Percentages!I9");
                        }
                        else
if(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP
Uncertainty
Percentages!B10")&&normalisedUncertainty<=excelFile1.getCellNumericVal
ue("NUSAP Uncertainty Percentages!C10")){

      uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP
Uncertainty Percentages!I10");
                        }
                        else
if(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP
Uncertainty
Percentages!B11")&&normalisedUncertainty<=excelFile1.getCellNumericVal
ue("NUSAP Uncertainty Percentages!C11")){

      uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP
Uncertainty Percentages!I11");
                        }
                        else
if(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP
Uncertainty
Percentages!B12")&&normalisedUncertainty<=excelFile1.getCellNumericVal
ue("NUSAP Uncertainty Percentages!C12")){

      uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP
Uncertainty Percentages!I12");
                        }

      uncertaintyCost=complexityCostValue*uncertaintyPercentage/100;

      complexityCostValue=complexityCostValue+2*uncertaintyCost;  //New
Complexity  cost  for  complexity  dimension  with  value  different  from
zero

      aggregatedComplexityCostValue=aggregatedComplexityCostValue+comp
lexityCostValue; // The sum of complexity costs for each complexity
dimension with value different from zero
```

```
                }
            }
        complexityCostActivityMod=aggregatedComplexityCostValue; // Most probable complexity cost for the activity
        }


        else if (excelFile1.getCellBooleanValue("WBS Activity Complexity (AL)",rowActivity,37)==false){
            for (column=4;column<=36;column++){
            // 33 cells are visited to evaluate whether they had a zero value or not. The following block of code will be executed 33 times
                if (excelFile1.getCellNumericValue(sheet,rowActivity,column)==0.0) {}


                else{
                    double complexityPercentageValue=excelFile1.getCellNumericValue(sheet,rowActivity,column);

        complexityCostValue=baseCost*complexityPercentageValue;

        normalisedUncertainty=excelFile1.getCellNumericValue(sheet,12,column);
                    // Uncertainty cost calculation
                    if (normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP Uncertainty Percentages!B8")&&normalisedUncertainty<=excelFile1.getCellNumericValue("NUSAP Uncertainty Percentages!C8")){

        uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP Uncertainty Percentages!I8");
                    }
                    else if(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP Uncertainty Percentages!B9")&&normalisedUncertainty<=excelFile1.getCellNumericValue("NUSAP Uncertainty Percentages!C9")){

        uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP Uncertainty Percentages!I9");
```

```
                        }
                        else
if(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP
Uncertainty
Percentages!B10")&&normalisedUncertainty<=excelFile1.getCellNumericVal
ue("NUSAP Uncertainty Percentages!C10")){

      uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP
Uncertainty Percentages!I10");
                        }
                        else
if(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP
Uncertainty
Percentages!B11")&&normalisedUncertainty<=excelFile1.getCellNumericVal
ue("NUSAP Uncertainty Percentages!C11")){

      uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP
Uncertainty Percentages!I11");
                        }
                        else
if(normalisedUncertainty>=excelFile1.getCellNumericValue("NUSAP
Uncertainty
Percentages!B12")&&normalisedUncertainty<=excelFile1.getCellNumericVal
ue("NUSAP Uncertainty Percentages!C12")){

      uncertaintyPercentage=excelFile1.getCellNumericValue("NUSAP
Uncertainty Percentages!I12");
                        }

      uncertaintyCost=complexityCostValue*uncertaintyPercentage/100;

      complexityCostValue=complexityCostValue+uncertaintyCost;    //New
Complexity cost for complexity dimension with value different from
zero

      aggregatedComplexityCostValue=aggregatedComplexityCostValue+comp
lexityCostValue; // The sum of complexity costs for each complexity
dimension with value different from zero
                  }
            }
      complexityCostActivityMod=aggregatedComplexityCostValue; // Most
probable complexity cost for the activity
      }
}
```

```
// Cost accuracy leading to a triangular distribution for Complexity cost

if (normalisedUncertainty>=excelFile1.getCellNumericValue("Cost accuracy Range!F8")&&normalisedUncertainty<=excelFile1.getCellNumericValue("Cost accuracy Range!G8")){

      rangeMinPercentage=excelFile1.getCellNumericValue("Cost accuracy Range!H8");

      rangeMaxPercentage=excelFile1.getCellNumericValue("Cost accuracy Range!I8");

      complexityCostActivityMin=complexityCostActivityMod*(1+rangeMinPercentage/100);

      complexityCostActivityMax=complexityCostActivityMod*(1+rangeMaxPercentage/100);

}

else if(normalisedUncertainty>=excelFile1.getCellNumericValue("Cost accuracy Range!F9")&&normalisedUncertainty<=excelFile1.getCellNumericValue("Cost accuracy Range!G9")){

      rangeMinPercentage=excelFile1.getCellNumericValue("Cost accuracy Range!H9");

      rangeMaxPercentage=excelFile1.getCellNumericValue("Cost accuracy Range!I9");

      complexityCostActivityMin=complexityCostActivityMod*(1+rangeMinPercentage/100);

      complexityCostActivityMax=complexityCostActivityMod*(1+rangeMaxPercentage/100);

}

else if(normalisedUncertainty>=excelFile1.getCellNumericValue("Cost accuracy Range!F10")&&normalisedUncertainty<=excelFile1.getCellNumericValue("Cost accuracy Range!G10")){

      rangeMinPercentage=excelFile1.getCellNumericValue("Cost accuracy Range!H10");

      rangeMaxPercentage=excelFile1.getCellNumericValue("Cost accuracy Range!I10");

      complexityCostActivityMin=complexityCostActivityMod*(1+rangeMinPercentage/100);

      complexityCostActivityMax=complexityCostActivityMod*(1+rangeMaxPercentage/100);

}
```

```
else    if(normalisedUncertainty>=excelFile1.getCellNumericValue("Cost accuracy Range!F11")&&normalisedUncertainty<=excelFile1.getCellNumericValue("Cost accuracy Range!G11")){

      rangeMinPercentage=excelFile1.getCellNumericValue("Cost  accuracy Range!H11");

      rangeMaxPercentage=excelFile1.getCellNumericValue("Cost  accuracy Range!I11");

      complexityCostActivityMin=complexityCostActivityMod*(1+rangeMinPercentage/100);

      complexityCostActivityMax=complexityCostActivityMod*(1+rangeMaxPercentage/100);

}

else    if(normalisedUncertainty>=excelFile1.getCellNumericValue("Cost accuracy Range!F12")&&normalisedUncertainty<=excelFile1.getCellNumericValue("Cost accuracy Range!G12")){

      rangeMinPercentage=excelFile1.getCellNumericValue("Cost  accuracy Range!H12");

      rangeMaxPercentage=excelFile1.getCellNumericValue("Cost  accuracy Range!I12");

      complexityCostActivityMin=complexityCostActivityMod*(1+rangeMinPercentage/100);

      complexityCostActivityMax=complexityCostActivityMod*(1+rangeMaxPercentage/100);

}


complexityCostActivity=triangular(complexityCostActivityMin,complexityCostActivityMax,complexityCostActivityMod);


return complexityCostActivity;
```